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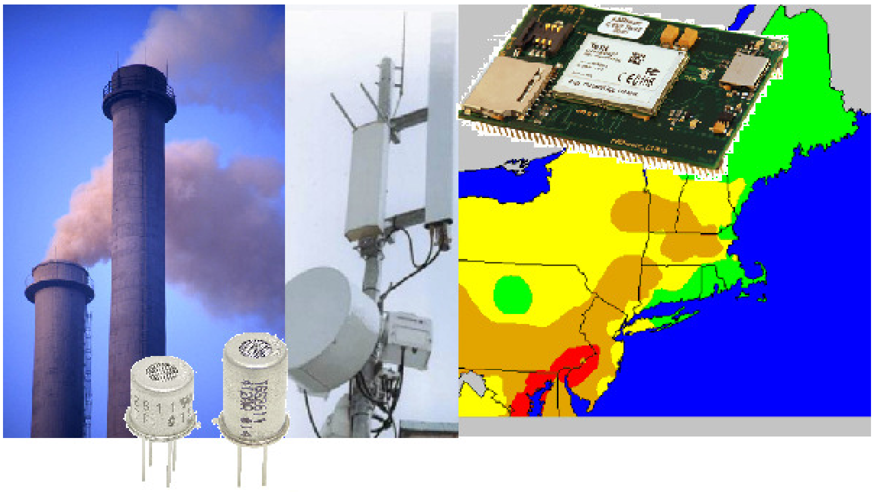

Mobile Station for Air Quality Mapping Sensor Network

Estação Móvel para Rede de Sensores de Mapeamento da Qualidade do Ar

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Master's Degree Dissertation in

Electronics Engineering

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Abstract

There are many ways to measure air pollution, based on chemical and physical methods. Most systems of measuring air quality actually in cites rely on fixed stations with the appropriate sensors and instrumentation to measure the air quality. These stations determine the pollution in the particular area where they are installed, and usually rely on methods of measurement that are somehow expensive. The stations for instance usually have dimensions that are not appropriate to change its geographical position. The aim of this work is to develop a mobile system, not too expensive, to be placed on the top of buses or taxis, making it possible to measure air quality in wide areas. The measurements are made through several sensors. The time and geographical position of the measurement is obtained through GPS (Global Positioning System), and the data collected from the station is transmitted to a central station through the GSM (Global System for Mobile Communications) network, or can be download from a nearby computer through the IEEE 802.11 (WIFI). This system also opens the possibility for creating geographical maps with the air quality information represented on the map, due to the wide area coverage than can be achieved by portable autonomous air quality monitoring stations.

Keywords:

Air quality monitoring, mobile stations, air pollution maps, embedded system, sensor networks.

Resumo

Existem muitas formas de medir a poluição atmosférica, com base em métodos químicos e físicos. A maioria dos sistemas para medir a qualidade do ar que se encontram actualmente em pratica nas cidades baseiam-se em estações fixas equipadas com os sensores e instrumentação apropriados para medir a qualidade do ar. Estas estações determinam a poluição nas áreas em que se encontram instaladas, e usualmente baseiam-se em métodos de medição que envolvem equipamento bastante caro. Estas estações, por exemplo, usualmente tem dimensões que fazem com que não sejam apropriadas para mudar a sua posição geográfica. O objectivo deste trabalho é o desenvolvimento de um sistema móvel, não muito caro, a ser instalado no tejadilho de autocarros e táxis, tornando possível medir a qualidade do ar em áreas vastas. As medições são feitas através de vários sensores, a hora e posição geográfica das medições é obtida através de GPS (Global Positioning System), e os dados recolhidos pela estação são transmitidos para uma estação central através de GSM (Global System for Mobile Comunications), ou podem ser copiados a partir de um computador nas proximidades através de IEEE802.11 (WIFI). Este sistema também abre a possibilidade para a criação de mapas geográficos com a informação sobre a qualidade do ar representada nos mapas, através da cobertura de grandes áreas que o sistema de estações portáteis permite alcançar.

Palavras-chave:

Monitorização da qualidade do ar, estações autónomas,mapas de poluição atmosférica, sistemas embebidos para redes de sensores.

Acronyms

ADC – Analog to Digital Converter

GPRS – General packet radio service

GPS – Global Positioning System

GSM – Global System for Mobile Communications

GPIO – General Purpose Input Output

I2C – Inter-Integrated Circuit, communications standard

IPv4 – Internet Protocol Version 4

IQAr – Air Quality Index

LAN – Local Area Network

MICS – MicroChemical Systems, SA

MII – Media Independent Interface

OTP – One Time Programmable

PIN – Personal Identification Number (secret code used to access the SIM card)

PM – Particulate Matter

RAM – Random Access Memory

SIM – Subscriber Identity Module (small card for mobile phones)

TGS – Taguchi Gas Sensor

UV – Ultraviolet

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Chapter 1 – Introduction

The project described in this report is about the remote measurement of air pollution, in urban areas. This project is done as a thesis in Electronics engineering of the Instituto Superior Tecnico, at TagusPark, it is integrated in a research project called Urbisnet, lead by ISR with the collaboration of Instituto de Telecomunicações and Instituto de Soldadura e Qualidade. This project is supported by FCT (Fundação para a Ciência e Tecnologia) under the contract PTDC/EEA-CRO/104243/2008.

1.1 – Purpose and Motivation

This report presents the development of a portable and low cost system, than can be used to measure air quality, in wide areas. It can be used to identify potential harmful situations quickly, giving time to act in accordance to minimize the damages and consequences, and aiding in identifying the causes and responsibilities of the air pollution problems.

A clean air supply is essential to our own health and that of the environment. Since the industrial revolution, the quality of the air we breathe has deteriorated considerably – mainly as a result of human activities. Rising industrial and energy production, the burning of fossil fuels and the rise in traffic on the roads, all contribute to air pollution in towns and cities, increasing the potential to health problems. For example, air pollution is increasingly being cited as the main cause of lung conditions such as asthma. There are also the concerns related to the effects that air pollution generated by human activity has in the natural ecosystems and the earth environment [1].

Since the system is equipped with CO and CO_2 sensors it might also be used to detect the presence of fires, with the application in surveillance and prevention of fires.

As a way of exemplifying the importance of monitoring air pollution, a set of problematic events related to air pollution is presented next.

- The problem of air pollution is not just a recent problem, people complaints are at least as old as from the 13th century when coal was first widespread used in London [2].

- Since the middle of the 19th century, the atmosphere of the major British cities was regularly polluted by coal smoke in winter, giving rise to an infamous mixture of fog and smoke known as smog. Extreme cases of the smog phenomena such as the Great Smog of '52 or Big Smoke, leave out no doubt that air pollution is a real threat to health, and can have significant effects on the population well being and activities. The main sources of pollution in this event were attributed to high coal usage to heating and electrical energy production, in particular low-grade, sulfurous variety, which increases the amount of sulfur dioxide (SO_2) in smoke, and a recent increase in diesel-fueled engines for transportation purposes in the affected area. The consequences of this condition during its one week duration were low, short range visibility, and is believed that a total of 12000 people have died in the months after this occurrence (Fig. 1.1).

- Since the Industrial Revolution than occurred around the 18th century, there has been a widespread use of coal and petroleum based fuels to heating, lighting, powering combustion engines, and other machinery, with the consequence of the undesired byproducts released into the air such as Sulfur oxides (SO_x), Nitrogen oxides (NO_x), Carbon Monoxide (CO), Carbon Dioxide (CO_2), various volatile organic compounds, Particulate matter (PM) are tiny particles of solid or liquid suspended in the air, ground level ozone (O_3), etc. These byproducts whether originated by natural processes (such as Vulcanos, or forest and grassland fires) or originated by human activity, can lead to negative health effects on the population (mainly the respiratory and cardiovascular system are the most affected), and can lead to differences in the air that can be smelled and seen, in extreme cases taking the form of smog [3].

Fig. 1.1 – Examples of smog on London UK and São Paulo Brazil.

- The 1997 Southeast Asian haze was a large air quality disaster which caused widespread atmospheric visibility and health problems within Southeast Asia. It had various economical losses due to mainly health care and disruption of air travel and business activities (Fig. 1.2). It was caused mainly by slash and burn techniques adopted by farmers in Indonesia. Slash and burn has been extensively used for many years as the cheapest and easiest means to clear the lands for traditional agriculture. Particulate matter (PM) was the predominant air pollutant responsible for the haze and degradation of air quality [5].

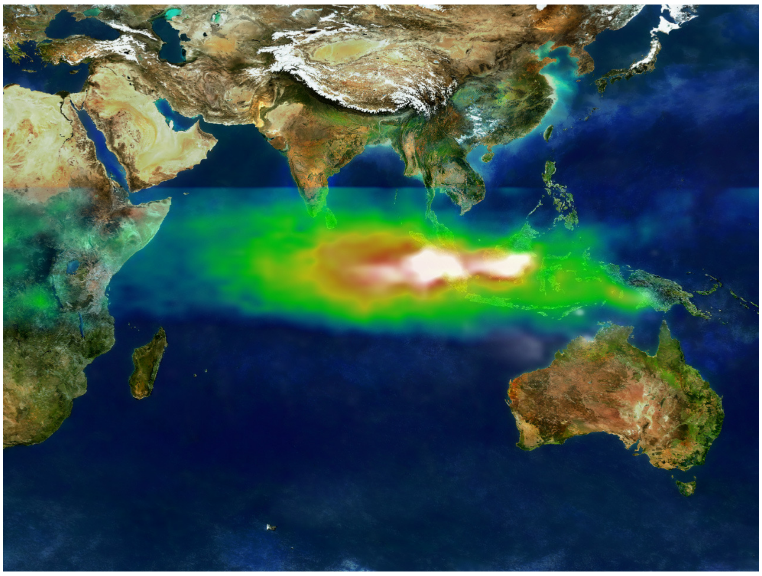

Fig. 1.2 – During the peak episode at October 1997, satellite imagery (NASA/TOMS aerosol index maps) showed a haze layer which expanded over an area of more than 3 million km^2, covering large parts of Sumatra and Kalimantan.

- Extreme situation like the Bhopal disaster was one of the worst industrial catastrophe occurred in the night of 2 December 1984 at the Union Carbide India Limited (UCIL) pesticide plant in Bhopal, Madhya Pradesh, India. Around midnight on 2 December of 1984, there was a leak of methyl isocyanate (C_2H_3NO) gas and other toxins from the plant, resulting in the exposure of over 500000 people. The government of Madhya Pradesh has confirmed a total of 3787 deaths related to the gas release [6].

1.2 Most Usual Air Pollutants

This sub-chapter has a lot of information on the atmosphere and its pollutants, it was compiled from searches on the Internet and some bibliography that I consulted, I tried to consult the sources that seemed the most trustful and knowledgeable, but I'm don't guaranty that all the information is completely accurate, as the information presented here isn't resultant from my work or research.

1.2.1 – Information about the atmosphere and units used to measure it

Air pollution means the presence in the exterior atmospheres of one or more contaminants, or their combination in quantities or with a duration such that can be harmful to human life, vegetable life, animal life, or property. The air contaminants include smokes, vapors, paper ashes, dust, soot, carbon smokes, gases, mist, radioactive materials and toxic chemical products [37].

Tab. 1.1 – Composition of dry atmosphere (by volume) in the troposphere area, (in accordance with the source Poluição Atmosférica (Um Manual Universitário) – João Gomes) .

Gas	**Concentration by volume**
Nitrogen (N_2)	78.08%
Oxygen (O_2)	20.95%
Argon	0.93%
Carbon dioxide	340 ppm
Neon	18.18 ppm
Helium	5.24 ppm
Methane	1.50 ppm
Krypton	1.14 ppm
Hydrogen	0.50 ppm
Nitrous Oxide	0.40 ppm
Xenon	0.09 ppm

The usual units used to measure gas concentration are ppm or mg/m^3 or $\mu g/m^3$, these are related by the equation

$$k = \frac{c[\mu g/m^3]}{c[PPM]} = (M \cdot P)/(R \cdot T) \quad . \qquad (1.1)$$

R – Universal constant for the gases (8.314 J/(mol•K))

T – Atmosphere temperature in Kelvin (K)

P – Atmospheric pressure (Pa)

M – Molar mass of the gas (g/mol)

Using the values stated and knowing the molar mass for each gas the flowing table is obtained.

Tab. 1.2 – Conversion factor form $\mu g/m^3$ to ppm, for T = 0ºC, at sea level, [$\mu g/(PPM \bullet m^3)$] .

Gas	k [$\mu g/(PPM \bullet m^3)$]
Hydrogen (H)	89
Helium (He)	178
Methane (CH_4)	712
Carbon Monoxide (CO)	1259
Ozone (O_3)	2140
Nitric Oxide (NO)	1960
Nitrogen dioxide (NO_2)	2050
Ammonia (NH_3)	760
Sulfur dioxide (SO_2)	2860
Hydrogen sulfide (H_2S)	1520

There are several units to measure temperature, the most used are Kelvin (K), Degrees centigrade (ºC). The temperature is related to the kinetic energy of the particles in a gas. For the simplification of the ideal monoatomic gas the relation between the temperature and the kinetic energy is given by

$$E_{int}=\text{Ktotal translation}=3nRT/2 \;. \tag{1.2}$$

(T – temperature in Kelvin, n – number of molecules in mol).

The relationship between centigrade degrees and kelvin degrees is

$$T[K]=T[^\circ C]+273.15 \;. \tag{1.3}$$

Relative humidity is defined as the ratio of the partial pressure of water vapor (in a gaseous mixture of air and water vapor) to the saturated vapor pressure of water at a given temperature. In other words, relative humidity is the amount of water vapor that is in the air at a specific temperature compared to the maximum amount of water vapor that the specific temperature is able to hold without the water condensing.

Relative humidity is expressed as a percentage and is calculated by the equation

$$\varphi=\frac{p(H_2O)}{p^*(H_2O)}\times 100\% \quad . \tag{1.4}$$

$p(H_2O)$ is the partial pressure of water vapor in the gas mixture;

$p^*(H_2O)$ is the saturation vapor pressure of water at the temperature of the gas mixture;

φ (also represented as RH) is the relative humidity of the gas mixture being considered.

1.2.2 – Nitrogen Oxides (also denominated No_x)

1.2.2.1 – Pollutant Sources (Nitrogen Oxides, No_x)

At ambient temperatures, the oxygen and nitrogen gases in air will not react with each other. In an internal combustion engine, combustion of a mixture of air and fuel produces combustion temperatures high enough to drive endothermic reactions between atmospheric nitrogen and oxygen in the flame, yielding various oxides of nitrogen. In areas of high motor vehicle traffic, such as in large cities, the amount of nitrogen oxides emitted into the atmosphere as air pollution can be quite significant. Nitrogen Oxides are pollutants emitted from stationary sources like combustion equipment and are composed essentially by Nitrogen Oxide (NO) and Nitrogen Dioxide (NO_2). Other source of NO_x can be cigarette smoke and power plants. In the gases obtained from combustion of fossil fuels, NO_2 is approximately inferior to 10% of the total NO_x produced. After the emission to the atmosphere the oxidation of the NO to NO_2 under the influence of the solar radiation happens.

1.2.2.2 – Pollutant Description (Nitrogen Oxides, No_x)

Nitrogen monoxide (systematic name) is a chemical compound with chemical formula NO. This gas is an important signaling molecule in the body of mammals, including humans, and is an extremely important intermediate in the chemical industry. Nitrogen dioxide is the chemical compound with the formula NO_2. One of several nitrogen oxides, NO_2 is an intermediate in the industrial synthesis of nitric acid, millions of tons of which are produced each year. This reddish-brown toxic gas has a characteristic sharp, biting odor and is a prominent air pollutant. Nitrogen dioxide is a paramagnetic bent molecule with C2v point group symmetry. When exposed to oxygen, NO is converted into nitrogen dioxide. This is given by the equation $2NO + O_2 \rightarrow 2NO_2$.

1.2.2.3 – Pollutant Hazards (Nitrogen Oxides, No_x)

Appropriate levels of NO production are important in protecting an organ such as the liver from ischemic damage. However sustained levels of NO production result in direct tissue toxicity and contribute to the vascular collapse associated with septic shock, whereas chronic expression of NO is associated with various carcinomas and inflammatory conditions including juvenile diabetes, multiple sclerosis, arthritis and ulcerative colitis. Nitrogen dioxide (NO_2) is toxic by inhalation, but this can be avoided as the material is acrid and easily detectable by smell. One potential source of exposure is fuming nitric acid, which spontaneously produces NO_2 above 0 °C. Symptoms of poisoning (lung edema) tend to appear several hours after one has inhaled a low but potentially fatal dose. Also, low concentrations (4 ppm) will anesthetize the nose, thus creating a potential for overexposure. Long–term exposure to NO_2 at concentrations above 40 – 100 $\mu g/m^3$ causes adverse health effects [11], [12].

1.2.3 – Sulfur dioxide (SO_2)

1.2.3.1 Pollutant Sources (Sulfur dioxide, SO_2)

Natural sources of sulfur dioxide include releases from volcanoes, oceans, biological decay and forest fires. The most important man-made sources of sulfur dioxide are fossil fuel combustion, smelting, manufacture of sulfuric acid, conversion of wood pulp to paper, incineration of waste and production of elemental sulfur. Coal burning is the single largest man-made source of sulfur dioxide accounting for about 50 % of annual global emissions, with oil burning accounting for a further 25% to 30 %.

1.2.3.2 – Pollutant Description (Sulfur dioxide, SO_2)

The Sulfur dioxide is a colorless gas, can be detected by its typical smell and taste. It reacts on the surface of a variety of airborne solid particles, is soluble in water and can be oxidized within airborne water droplets. Sulfur dioxide, a product of the combustion of sulfur containing fossil fuels, plays an important role in atmospheric corrosion in urban and industrial type atmospheres. It is adsorbed on metal surfaces, has a high solubility in water and tends to form sulfuric acid (acid rain) in the presence of moisture films. Sulfate ions are formed in the surface moisture layer by the oxidation of sulfur dioxide and their formation is considered to be the main corrosion accelerating effect from sulfur dioxide.

1.2.3.3 – Pollutant Hazards (Sulfur dioxide, SO_2)

The major health concerns associated with exposure to high concentrations of sulfur dioxide include effects on breathing, respiratory illness, alterations in pulmonary defenses, and aggravation of existing cardiovascular disease. In the atmosphere, sulfur dioxide mixes with water vapor producing sulfuric acid. This acidic pollution can be transported by wind over many hundreds of miles, and deposited as acid rain [21].

1.2.4 – Carbon dioxide (CO_2)

1.2.4.1 – Pollutant Sources (Carbon dioxide, CO_2)

CO_2 is a trace gas (1) comprising 0.039 % of the atmosphere. Carbon dioxide is used by plants during photosynthesis to make sugars, which may either be consumed in respiration or used as the raw material to produce other organic compounds needed for plant growth and development.

(1) – A trace gas is a gas which makes up less than 1% by volume of the Earth's atmosphere, and it includes all gases except nitrogen (78.1%) and oxygen (20.9%).

It is emitted during respiration by plants, and by all animals, fungi and microorganisms that depend either directly or indirectly on plants for food. Carbon dioxide is generated as a by-product of the combustion of fossil fuels or the burning of vegetable matter, among other chemical processes. Amounts of carbon dioxide are emitted from volcanoes and other geothermal processes such as hot springs and geysers and by the dissolution of carbonates in crustal rocks.

1.2.4.2 – Pollutant Description (Carbon dioxide, CO_2)

Carbon dioxide is colorless. At low concentrations, the gas is odorless. At higher concentrations it has a sharp, acidic odor. Above –78.51° C or –109.3° F, carbon dioxide changes directly from a solid phase to a gaseous phase through sublimation, or from gaseous to solid through deposition. Solid carbon dioxide is normally called "dry ice", a generic trademark. It was first observed in 1825 by the French chemist Charles Thilorier. Dry ice is commonly used as a cooling agent, and it is relatively inexpensive. A convenient property for this purpose is that solid carbon dioxide sublimes directly into the gas phase leaving no liquid. Liquid carbon dioxide forms only at pressures above 5.1 atm; the triple point of carbon dioxide is about 518 kPa at –56.6 ℃. Carbon dioxide is a greenhouse gas as it transmits visible light but absorbs strongly in the infrared and near-infrared. Greenhouse gases greatly affect the temperature of the Earth; without them, Earth's surface would be on average about 33 ℃ (59 ℉)colder than at present.

1.2.4.3 – Pollutant Hazards (Carbon dioxide, CO_2)

At low concentrations, the gas is odorless. At higher concentrations it has a sharp, acidic odor. It will act as an asphyxiant and an irritant. When inhaled at concentrations much higher than usual atmospheric levels, it can produce a sour taste in the mouth and a stinging sensation in the nose and throat. These effects result from the gas dissolving in the mucous membranes and saliva, forming a weak solution of carbonic acid. Amounts above 5,000 ppm are considered very unhealthy, and those above about 50,000 ppm (equal to 5% by volume) are considered dangerous to animal life.

Toxicity and its effects increase with the concentration of CO_2, here given in volume percent of CO_2 in the air:

- 1% can cause drowsiness with prolonged exposure.
- At 2% it is mildly narcotic and causes increased blood pressure and pulse rate, and causes reduced hearing.
- At about 5% it causes stimulation of the respiratory center, dizziness, confusion and difficulty in breathing accompanied by headache and shortness of breath. Panic attacks may also occur at this concentration [13].
- At about 8% it causes headache, sweating, dim vision, tremor and loss of consciousness after exposure for between five and ten minutes [13].

1.2.5 – Carbon monoxide (CO)

1.2.5.1 – Pollutant Sources (Carbon monoxide, CO)

Carbon monoxide is produced from the partial oxidation of carbon-containing compounds; it forms when there is not enough oxygen to produce carbon dioxide (CO_2), such as when operating a stove or an internal combustion engine in an enclosed space. Carbon monoxide burns with a blue flame, producing carbon dioxide. Worldwide, the largest source of carbon monoxide is natural in origin, due to photochemical reactions in the troposphere which generate about 5 x 10^{12} kilograms per year (in accordance with the source "Carbon Monoxide Balance in Nature - Bernard Weinstock and Hiromi Niki, Scientific Research Staff, Ford Motor Company, Dearborn, Michigan 48121"). Other natural sources of CO include volcanoes, forest fires, and other forms of combustion. Anyway in clean air the usual concentration of Carbon Monoxide (CO) is lower than 1ppm.

1.2.5.2 – Pollutant Description (Carbon monoxide, CO)

Carbon monoxide is a gas with no smell, colorless, tasteless gas. Because it's high level of toxicity it was one of the first gases to be investigated. Its melting point is –205ºC, and it's boiling is –191.5ºC. The bond length between the carbon atom and the oxygen atom is 112.8 pm. The bond length of CO is consistent with a partial triple bond, and the molecule can be represented by three resonance structures (Fig. 1.3).

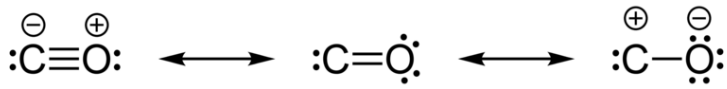

Fig. 1.3 – Resonance structures of the CO molecule.

1.2.5.3 – Pollutant Hazards (Carbon monoxide, CO)

Carbon monoxide poisoning is the most common type of fatal air poisoning in many countries. Carbon monoxide is colorless, odorless and tasteless, but highly toxic. It combines with hemoglobin to produce carboxyhemoglobin, which is ineffective for delivering oxygen to bodily tissues. This condition is known as anoxemia. Concentrations as low as 667 ppm may cause up to 50% of the body's hemoglobin to convert to carboxyhemoglobin. In the United States, the OSHA limits long-term workplace exposure levels above 50 ppm. The most common symptoms of carbon monoxide poisoning may resemble other types of poisonings and infections (such as the flu), including headache, nausea, vomiting, dizziness, fatigue and a feeling of weakness. Infants may be irritable and feed poorly. Neurological signs include confusion, disorientation, visual disturbance, syncope and seizures. Carbon monoxide binds to other molecules such as myoglobin and mitochondrial cytochrome oxidize. Exposures to carbon monoxide may cause significant damage to the heart and central nervous system, especially to the globus pallidus, often with long-term sequelae. Carbon monoxide may have severe adverse effects on the fetus of a pregnant woman [19], [20].

1.2.6 – Ozone (O_3)

1.2.6.1 – Pollutant Sources (Ozone, O_3)

(in accordance with the source http://www.epa.gov/glo/)

It is not usually emitted directly into the air, but at ground-level is created by a chemical reaction between oxides of nitrogen (NO_x) and volatile organic compounds (VOC) in the presence of sunlight.

Ozone has the same chemical structure whether it occurs miles above the earth or at ground-level and can be "good" or "bad," depending on its location in the atmosphere. In the earth's lower atmosphere, ground-level ozone is considered "bad." Motor vehicle exhaust and industrial emissions, gasoline vapors, and chemical solvents as well as natural sources emit NO_x and VOC that help form ozone. Sunlight and hot weather cause ground-level ozone to form in harmful concentrations in the air. As a result, it is known as a summertime air pollutant. Many urban areas tend to have high levels of "bad" ozone, but even rural areas are also subject to increased ozone levels because wind carries ozone and pollutants that form it hundreds of miles away from their original sources [14].

"Good" ozone occurs naturally in the stratosphere approximately 10 to 30 miles (16km to 48km) above the earth's surface and forms a layer that protects life on earth from the sun's harmful rays.

The ozone gas (O_3) can also be formed from subjecting ozone to electrical discharges, like what happens in a lightning storm.

Formation of O_3 from O_2 molecules:

(in accordance with the source

http://www.columbia.edu/itc/chemistry/chem-c2407/hw/ozone_kinetics.pdf)

Chapman mechanism:

The original mechanism for atmospheric ozone formation and destruction from oxygen species was suggested by Chapman in 1930. The elementary reactions which constitute the

The Chapman mechanisms are:

$O_2 + hv \rightarrow 2O$, with rate constant k_1 (s^{-1}) . (1.5)

$O + O_2 + M \rightarrow O_3 + M$, with rate constant k_2 ($cm^6 \bullet molecule^{-2} \bullet s^{-1}$) (1.6)

$O_3 + hv \rightarrow O + O_2$, with rate constant k_3 (s^{-1}) (1.7)

$O + O_3 \rightarrow 2O_2$, with rate constant k_4 (cm^3 $molecules^{-1} \bullet s^{-1}$) (1.8)

M is any non-reactive species that can take up the energy released in reaction ($O+O_2+M \rightarrow O_3+M$) to stabilize O_3. O_3 is not a very stable molecule and (without the presence of M) the O_3 formed by the collision of O_2 and O would immediately fall apart to give back O and O_2. Given that N_2 and O_2 are the major components in the atmosphere, M is either O_2 or N_2. The rate constants k_1 and k_3 depend on light intensity, which in this case is the light intensity of the sun. The rate constants $k_?$ measure how fast each reaction happens, all the reactions are continually happening, the concentration of the gases in the atmosphere depends on the relationships between these constants.

The formation of O_3 from NO_2 molecules, is $NO_2 + hv \rightarrow NO + O$, this reaction also happens in the atmosphere in the case were the molecule NO_2 is present. So this can also produce the single O atoms needed to the formation of ozone, and can be seen as a replacement for the equation $O_2+hv \rightarrow 2O$ in the formation of ozone, however the reactions $O_2+hv \rightarrow 2O$ and $NO_2 + hv \rightarrow NO + O$ can happen simultaneously all contributing to the formation of ozone (O_3) [15].

1.2.6.2 – Pollutant Description (Ozone, O_3)

In the atmosphere ozone is a toxic light-blue. It has a great oxidant power, and can oxidize all the common metals, with the exception of gold and palatine. This gas is a secondary pollutant. Ozone (O_3) is a gas composed of three oxygen atoms. Ozone has the same chemical structure whether it occurs miles above the earth or at ground-level and can be "good" or "bad," depending on its location in the atmosphere. Ground-level ozone is the primary constituent of smog. Ozone absorbs ultra-violet radiation (Fig. 1.4).

Absorption of the Sun's ultra-violet radiation during ozone formation and destruction in the stratosphere has three important consequences:

- less ultra-violet radiation reaches the lower parts of the atmosphere and, as a consequence, the surface of the Earth is protected from damaging radiation.
- since ultra-violet radiation is important for both ozone formation and destruction, the amount of ozone that can accumulate is limited - as ozone formation increases, ozone destruction also increases.
- ultra-violet radiation is highly energetic. This energy is transformed to heat during reaction leading to a warming of the stratosphere. This is the reason why the temperature trend in the stratosphere is opposite to that seen in the troposphere.

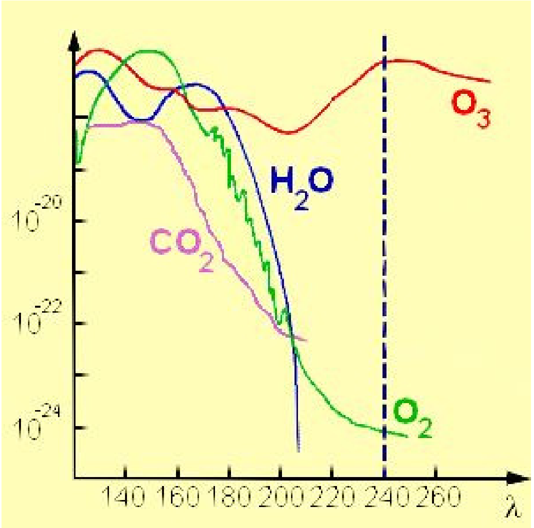

Fig. 1.4 – Absorption of ultra-violet radiation by ozone and other compounds in the stratosphere [16].

1.2.6.3 – Pollutant Hazards (Ozone, O_3)

The same chemical properties that allow high concentrations of ozone to react with organic material outside the body give it the ability to react with similar organic material that makes up the body, and potentially cause harmful health consequences. When inhaled, ozone can damage the lungs. Relatively low amounts can cause chest pain, coughing, shortness of breath, and, throat irritation. Ozone may also worsen chronic respiratory diseases such as asthma and compromise the ability of the body to fight respiratory infections. People vary widely in their susceptibility to ozone. Healthy people, as well as those with respiratory difficulty, can experience breathing problems when exposed to ozone. Ozone also strikes the C=C bonds of rubber, when in large concentrations, and can be responsible of cracks in this type of materials [14], [15].

1.3 – Legislation of air pollution

With the propose to define and establish objectives to the environment air, the framework directive 96/62/CE, created the base principles to a common strategy, as a way of preventing and reducing the noxious effects to human health and the environment, and also to evaluate the air quality in EU-member states, and inform the general public. This was planned to be achieved through threshold values to alarm situations, and the improvement of the environment air in the situations where it is not satisfactory. The base principles defined in the directive are: The definition of objectives to the quality of environment air, establish common methods and criteria of air quality evaluation, gather information about air quality and disclose (spread) the information, assure that air quality is good, and implement corrective strategies whenever it's found that air quality isn't in accordance with the standards. After this directive several decree/laws were emitted (in the Portuguese Republic). This documents regulates the competent authorities, were it is described the appropriate measures in order to achieve the objectives of the management policy of air quality, threshold values of the pollutant emissions to industrial facilities, reference and threshold values for each pollutant gas, and also many other aspects [18], [23].

The values of threshold used to evaluate air pollution are presented on the table 1.3.

Tab. 1.3 – Concentration classes associated to the IQAr (air quality index) for each pollutant (year 2005), source Agência Portuguesa do Ambiente. The designations in Portuguese are: Bad-Mau, Weak-Fraco, Average-Médio, Good-Bom, Excellent-Muito Bom. (min stands for minimum, and max stands for maximum).

Class \ Pollutant	NO_2 (µg/m^3)		O_3 (µg/m^3)		PM10 (µg/m^3)		SO_2 (µg/m^3)		CO (µg/m^3)	
	min	max	min	max	min	max	min	max	min	max
Bad	400	-	240	-	120	-	500	-	10000	-
Weak	250	399	180	239	50	119	350	499	8500	9999
Average	140	249	120	179	35	49	210	349	7000	8499
Good	100	139	60	119	20	34	140	209	5000	6999
Excellent	0	99	0	59	0	19	0	139	0	4999

Chapter 2 – State of the Art

2.1 – Sensor types / methods for measurement of air pollution

There are many ways to measure air pollution, based simply on chemical and physical methods, or with more sophisticated procedures that include some electronics. All gas sensors used in this work are off-the-shelf. A brief overview of the principles used are presented below to justify the signal conditioning used and to make clear the origin off the limitations of the complete system in measuring air quality.

2.1.1 – Electrochemical cells

An electrochemical cells, is a type of fuel cell that instead of being designed to produce power, is designed to produce a current that is precisely related to the amount of the target gas (the gas to be measured) in the atmosphere. By measuring the current in the cell one can calculate the amount of gas present at the atmosphere. For example, for carbon monoxide detection, the electrochemical cell has advantages over other technologies in that it has a highly accurate and linear output to carbon monoxide concentration, requires minimal power as it is operated at room temperature, and has a long lifetime. Typically commercial available cells now have lifetimes of 5 years or greater.

2.1.2 – Light absorption

Light can be used to determine the concentration of a specific gas using an apparatus that measures the amount of electromagnetic radiation that a gas absorbs compared to the amount of electromagnetic radiation that the atmosphere absorbs in the absence of the gas being measured. The usual name for the machine that makes these measurements is spectrophotometer. In accordance with the quantum theory of physics, the electrons present in an atom or molecule can only have a set of precise and discrete values for its potential energy. As the electrons in an atom or molecule can only change their energy state by absorbing a photon with the appropriate energy, so that the electrons change from their rest orbitals to another allowed higher energy orbitals (excited state). The allowed orbitals depend on the atom or molecule being measured, and each atom or molecule has a specific set of allowed orbitals, each with its specific potential energy. This set of allowed orbitals can be discovered by stimulating the substance with the appropriate electromagnetic radiation to make the electrons change their energy states, thus absorbing only the photons that have the amount of energy appropriate to make the electrons change the orbitals. The energy (E) of the photons is related to the frequency (f) of the electromagnetic radiation they are part of, by the relation $E=h \cdot f$ (where h is the Plank constant). This means that for each atom or molecule there will be a set of precise and discrete values for the frequency of the electromagnetic radiation that it can absorb. This set of frequencies is usually called the absorption spectrum of the substance, and is very useful for precisely identifying a substance.

A spectrophotometer works by stimulating a sample of the atmosphere with the appropriate radiation to measure a target gas and compares it with a sample of the same atmosphere without the target gas, the amount of radiation absorbed by the atmosphere to be sampled is proportional to the amount of the target gas in the atmosphere (Fig. 2.1) [24].

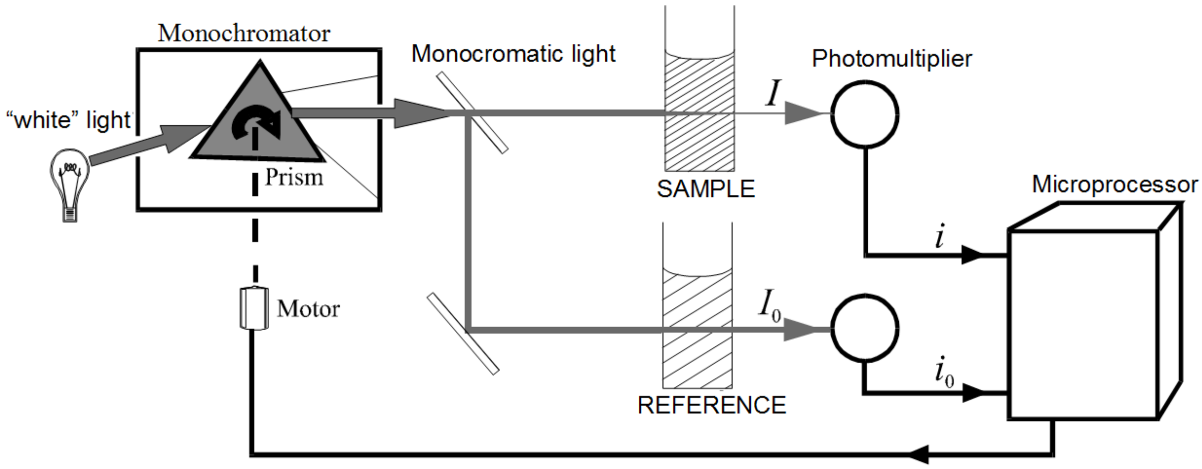

Fig. 2.1 - Spectrophotometer simplified block diagram (Reproduced from "Guia de Laboratórios de QUÍMICA GERAL, Publicação de Eurico Melo").

2.1.3 – Metal oxide semiconductor

These sensors are based on semiconductor materials. The sensing material is metal oxide, usually Tin Dioxide (SnO_2). When it is heated at a certain high temperature in air (about 400º C), oxygen is adsorbed on the crystal surface with a negative charge. Donor electrons in the crystal surface are transferred to the adsorbed oxygen, resulting in leaving positive charges in a space charge layer. Thus, surface potential in the semiconductor material is formed to serve as a potential barrier against electron flow (Fig. 2.2).

The spontaneous electron transfer from the metal oxide to the Oxygen gas is in accordance with the octet rule that states that atoms tend to combine in such a way that they each have eight electrons in their valence shells, giving them the same electronic configuration as a noble gas, and also because the metal oxide surface is purposely heat by the heater resistor placed inside the sensor increasing the energy of the electrons of the metal oxide. Inside the sensor, electric current flows through the conjunction parts (grain boundary) of SnO_2 micro crystals. At grain boundaries, adsorbed oxygen forms a potential barrier which prevents carriers from moving freely. The electrical resistance of the sensor is attributed to this potential barrier. In the presence of a deoxidizing gas, the surface density of the negatively charged oxygen decreases, so the barrier height in the grain boundary is reduced (Fig. 2.2). The reduced barrier height decreases sensor resistance.

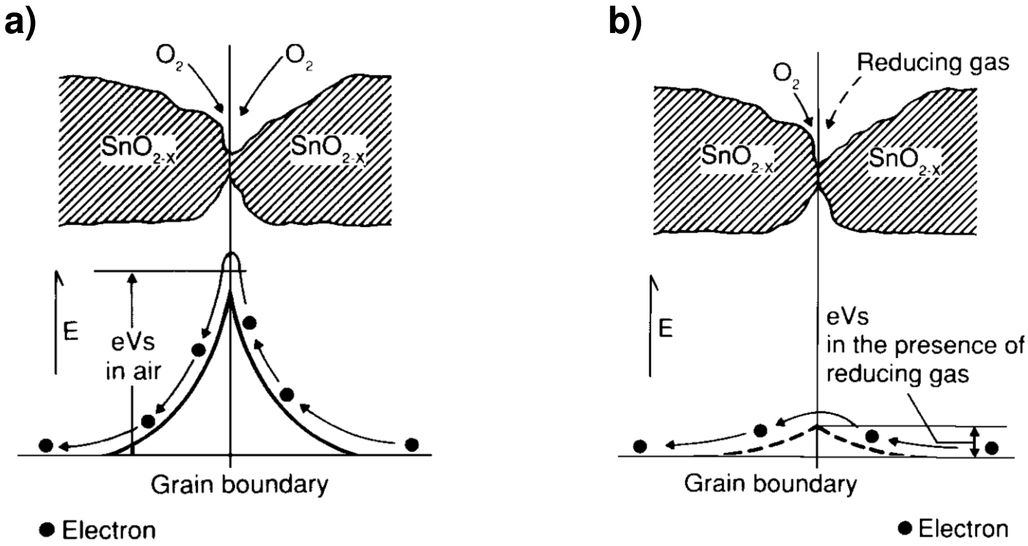

Fig. 2.2 – a) Model of inter-grain potential barrier (in the absence of gases), b) Model of inter-grain potential barrier (in the presence of gases).

The relationship between sensor resistance and the concentration of deoxidizing gas can be expressed over a certain range of gas concentration by the equation

$$R_s = A \cdot [C]^{-\alpha} \quad . \qquad (2.1)$$

R_s – Electrical resistance of the sensor,

A, α – characteristic constants,

[C] – gas concentration in ppm (parts per million),

R_o – Electrical resistance of the sensor (R_s) at reference environment conditions.

Figure 2.3 shows the characteristic behavior of a sensor of this type, namely a Taguchi Gas Sensors (TGS):

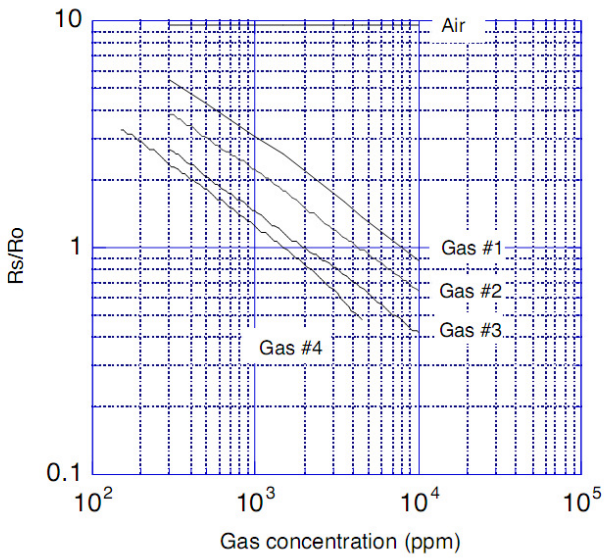

Fig. 2.3 – TGS Typical sensitivity characteristics.

This type of sensor is somewhat sensitive to air temperature and hu7midity, as can be seen in Fig. 2.4

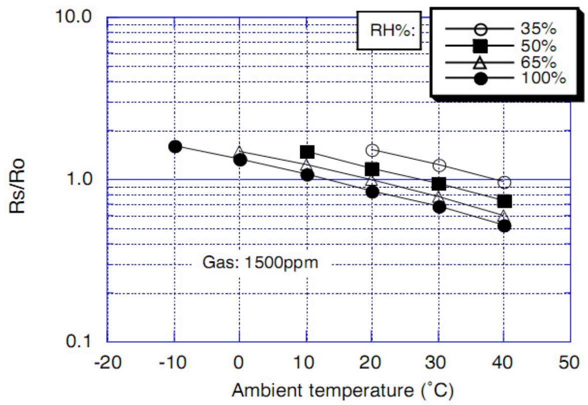

Fig. 2.4 - Typical temperature and humidity dependency.

These kind of sensors have the following advantages related to the objectives of this work [22]:

Advantages to the actual application:

- Low power consumption.
- Good sensitivity to gaseous air contaminants.
- Long life and low cost.
- Uses simple electrical circuit.
- Small size.

For these sensors the disadvantages are:

- Non linear relationship of the electrical output with the gas concentration (in ppm).
- Usually each sensor is sensible to a large variety of gases, which makes impossible gas

identification with only one sensor, and somehow challenging with the conjugation of the measurements form various sensors.

2.1.4 – Other methods

There are reliable sampling methods to measure air pollution which gives a good indication of average pollution concentrations over a period of weeks or months. These usually use physical or chemical methods to collect polluted air, and analysis is carried out later in the laboratory. Typically a known volume of air is pumped through a collector (such as a filter, or a chemical solution) for a known period of time. The collector is later removed for analysis. The tubes are manually distributed, collected, and analyzed in a laboratory. Obviously this type of air quality measurement isn't compatible with the kind of system being proposed, that must be autonomous and portable, so the methods used in the current work are different.

Fig. 2.5 - Standard diffusion tubes form Radiello.

There are also opto-chemical sensors, these consist of a pad of a colored chemical which changes upon reaction with gas to be detected. They only provide a qualitative warning of the gas, the advantage of these sensors are their low cost. For obvious reasons these sensors are also not appropriate to measure the gas concentration in an autonomous portable station.

2.2 – Available systems to monitor air quality in Urban areas

The conventional systems to monitor air pollution in urban areas are based in container style monitoring stations, or also mobile station incorporated in a modified trailer to accommodate the instruments and air circuits. These stations have a large size and usually their construction involves a large cost. Most of the data collected by the stations is transmitted to a central database, not requiring personnel to operate the stations, but the methods used usually require some maintenance and calibration process that can be made only by qualified personnel. The advantages of those stations are the methods used are very precise and selective for the measurement of the different gases.

2.2.1 – Non-portable system

The average size of the majority of the stations currently used in Air Quality monitoring networks, are about $16m^3$ (4m × 2m × 2m). There are some reduced size versions of this station but the size mentioned is the usual and is actually necessary to accommodate the instruments (usually there is a distinct instrument for each type of gas to be monitored by the station), and other equipment used for the operation of the station, such as pure gas cylinder used for the calibration of the instruments, air pump for the air circuits used to connect the samplers placed on the roof of the station to the individual measurement instruments, computer to remotely command the instruments, read the results and send the data to a central database, etc... The fixed stations based on this kind of structure can require a lot of space for all the apparatus as can be seen on Fig. 2.7 and 2.8.

Fig. 2.6 – Outside of the fixed station to monitor air pollution at Laranjeiro, part of Rede de Qualidade do Ar de Lisboa e Vale do Tejo.

Fig. 2.7 – Outside of a mobile station to monitor air pollution, property of Escola Superior de Tecnologia e Gestão de Leiria.

The manufacturer of PM10 measurement instrument (Environment SA is the usual manufacturer of the instruments used in Portuguese stations) states that its instruments has a power consumption of 330 W (pump included). Each station usually has at least 4 of this kind of instruments, one instrument for each type of air pollutant (the PM10 is the one with higher power consumption because of its heavy use of air circuits). In addition, those instruments usually use a computer for control and data transmission, a air pump, some extra sensors (eg. temperature), and sometimes also a air conditioning system, etc..., According to my estimations the average power consumption for a station of this kind must be in the order of the 1000 W.

The usual methods used to measure Air pollutants are:

(Although there are other possible methods for the measurement of the same pollutants presented here.)

- PM10 – Tapered Element Oscillating Microbalance, Beta Attenuation monitor, Gravimetric monitor
- CO – IR Absorption
- SO_2 – UV fluorescence
- O_3 – UV absorption
- NO/NO_x – Chemiluminescence

These methods usually require expensive equipment that occupies large amounts of space, and has high power consumption due to the air pumps, motors, valves to make the air flow (see Fig. 2.8 as an example). The methods listed usually require some maintenance and calibration process that can be made only by qualified personnel.

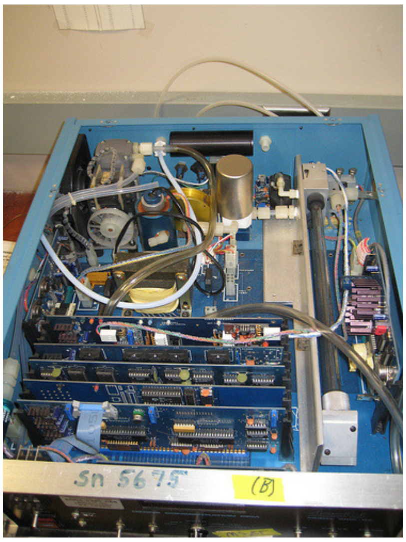

Fig. 2.8 – Dasibi ozone UV absorption meter inside view.

2.1.2 – Portable systems

There are also compact systems, similar to the one developed at this project, which are equipped with gas sensors, and geographic positioning systems, and communication systems. The company Libelium has stations that are modular. Modules can be assembled to have a system with an 8MHz microprocessor, 8KB RAM, 128 KB flash memory, GPS module, GSM/GPRS module, 802.15.4 zigbee. These station have the following sensors available to be mounted CO, CO_2, CH_4, O_2, H_2, NH_3, C_4H_{10}, CH_3CH_2OH, $C_6H_5CH_3$, H_2S, NO_2, O_3, Volatile organic compounds, Hydrocarbons, atmospheric pressure, humidity and temperature (Fig. 2.9).

The sensors used on the Libelium stations are metal oxide semiconductor sensors, which are low cost and compact, but not very selective, and not very accurate for low gas concentrations (Fig. 2.10).

The stations made by Libelium are quite similar to the specification required by the project proposed but miss some of the requirements of the Urbisnet project, for example being equipped with a more powerful processor, having a computer running an operating system, having a wifi (IEEE 802.11) interface [33].

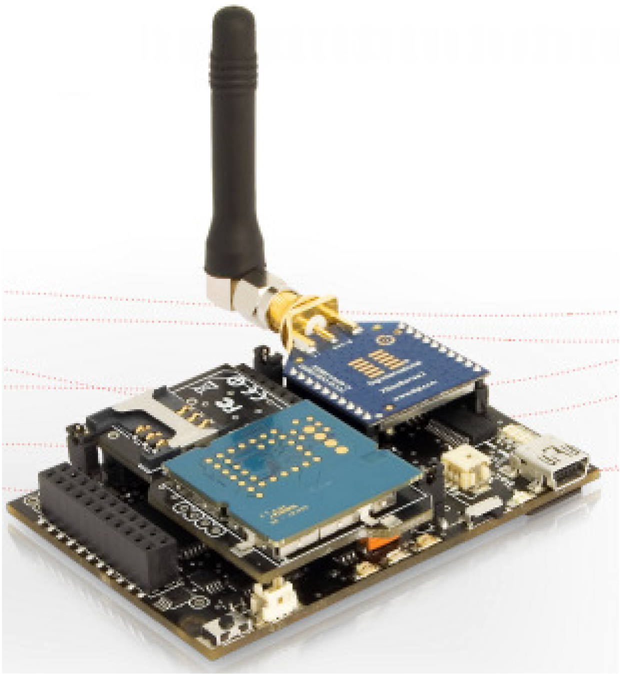

Fig. 2.9 – Libelium Waspmote station, with GSM, zigbee, GPS, 8-bit microprocessor.

Fig. 2.10 – Libelium gas sensor board to be used with the waspmote.

Chapter 3 – Hardware System Design

3.1 – System Architecture

The purpose of this work was to create a mobile air quality monitoring station.

The main requisites for the system were low cost, portability and the capability of storing measurement data locally and transmitting the capability of storing measurement data locally and transmuting it remotely using a wireless interface. Another requirement was time and location stamping of the gas measurements. A significant computational power was desired for use in future application in volume data fusion and signal processing algorithms.

The best way to achieve these goals is by using a digital system that can store sensor data correspondent to large periods of time, and that can be integrated with the existent technology to make possible the transmission of the data to a central station. It was determined that the following hardware components had to be used and integrated into a single system:

- Gas sensors (CO_2, CO, O_3, SO_2, NO_2)
- Temperature and humidity sensors
- Analog-to-Digital conversion
- Microprocessor
- Data storage
- WiFi and GPRS communication systems
- Global Positioning System receiver module

The architecture of the system is illustrated at Fig. 3.1.

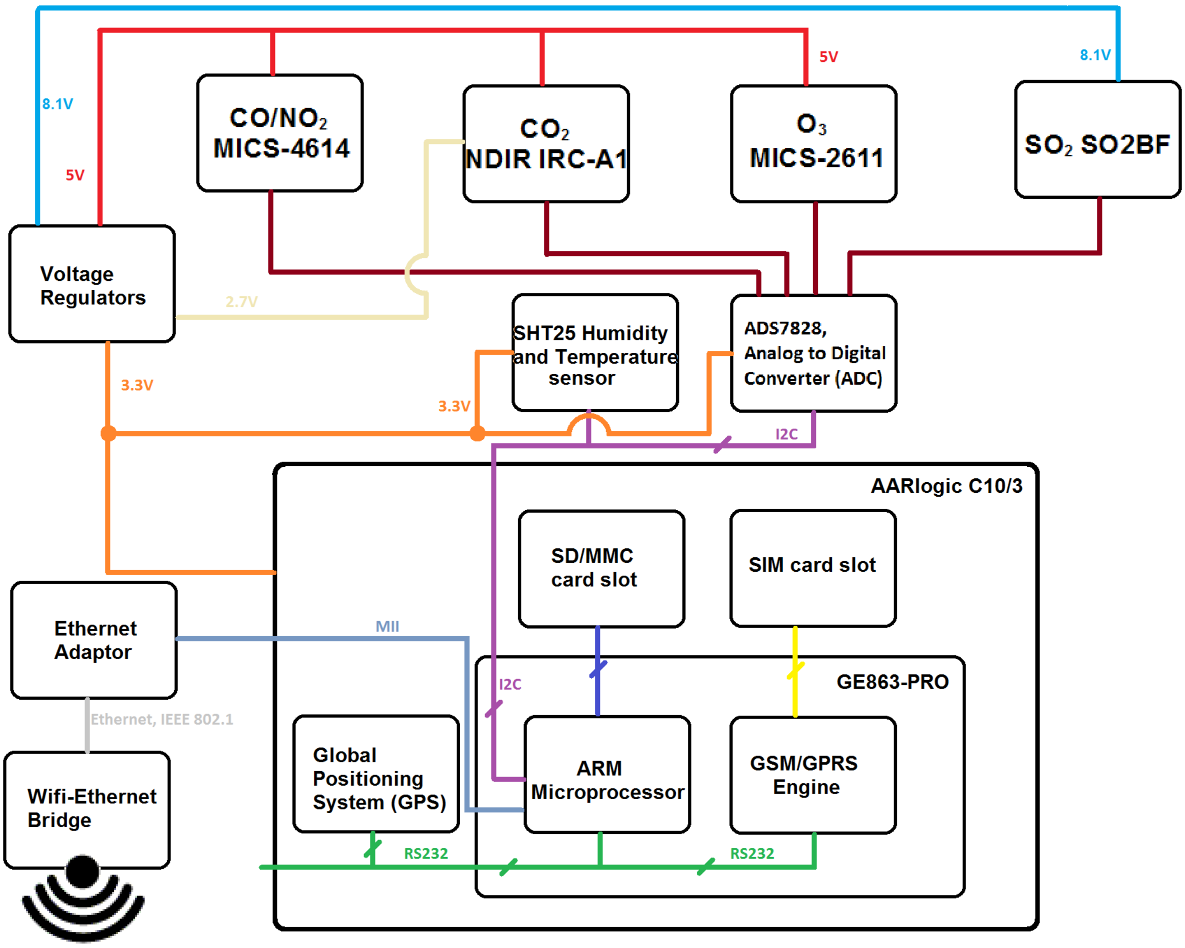

Fig. 3.1 – Functional diagram of the air quality monitoring station.

3.2 – Selection of the hardware and components of the monitoring station

The selection of the hardware to use took into account the energy consumption and the need for a moderate cost of the monitoring station to allow for large scale use for the creation of pollution maps. As in any newly developed system there is a tradeoff between using off-the-shelf components or developing them from scratch. The first design decision made was to acquire a module containing the microprocessor and as much of the required components as necessary. Since the field of embedded system is a thriving one there are a lot of commercially available options to choose from.

One of the project specification that was imposed by the project coordination was that this project should have a microprocessor capable of running an operating system (This is because it has been already done another version of this project were there was present only a microcontroler and the project coordination has concluded that was advantageous to have a microprocessor capable of running an operating system).

A search was made and the choice was narrowed down to two boards: one from Gumstix (http://www.gumstix.com), and another from Round Solutions (http://www.roundsolutions.com). In the selection of the main board the one found to be more cost effective and appropriate for the project was the board C10/3 from Round Solutions (see Table 2.1 for a side by side comparison). Another interesting board that was considered was the board Overo Fire from Gumstix, although it had the disadvantage of not having all the necessary modules incorporated.

Tab. 3.1 – Comparison table for Gumstix Overo Fire and Round Solutions C10/3.

	Gumstix Overo Fire	**Round Solutions C10/3**
Processor	Texas Instruments OMAP 3530 Applications Processor: ARM Cortex-A8 CPU, 720MHz C64x+ digital signal processor (DSP) core POWERVR SGX for 2D and 3D graphics acceleration Up to 1200 Dhrystone MIPS	ARM 9 integrated (200 MIPS) (Core AT91SAM9260)
Memory	256MB RAM 256MB Flash	64 MB RAM 4 MB (up to 128MB onboard)

	microSD card slot	Data Flash (Non volatile) SD card or MMC card slot
Inputs/Outputs	(2) 70-pin connectors with 140 signals for: I2C, PWM lines (6), A/D (6), UART, SPI, Extra MMC lines Headset, Microphone Backup battery High Speed USB Host and USB OTG (1) 27-pin connector with signals for camera board (2) x u.fl antenna connectors	Serial CMOS, JTAG, USB, I2C, SPI, General purpose input/output (GPIO), AD/DA converter
Global Positioning System (GPS)	N/A	AarLogic GPS 3M (SiRF 3/LP)
GSM/GPRS	N/A	GE863-PRO[3], QUAD-BAND
Networking technologies	802.11b/g wireless Bluetooth communications	Ethernet
Other Features	OMAP3530 Application Processor communications TPS65950 Power Management	Battery Charging electronic on board
Price	166,00 €	192,00 €

The main reason that leads to the choice of the Round Solutions C10/3 board was the presence of GPS and GSM/GPRS modules. This leads to an easier development, smaller volume and lower energy consumption. The reaming elements required for the station are the sensors and the WiFi communications.

The humidity and temperature sensor that was chosen was the Sensirion SHT25, it measures temperature and Humidity, and has a digital interface trough I2C. It has 12bit for the temperature measurement, and 14bit for the humidity measurement. The accuracy is $\pm$1.8% RH for relative humidity, and is $\pm$0.3% for relative temperature.

The gas sensors are described below. Signal conditioning electronics had to be developed for each one of them. Their output is analog which leads to the need of an analog-to-digital converter (ADC). Although the Round Solution module integrates an ADC it was not possible to make it work. Also it has only 4 channels which would make necessary the use of an external analog multiplexer (5 channels needed). The choice was then to acquire and use an external multichannel ADC (more below) to interface the gas sensors with the microprocessor.

The WiFi communications is going to be implemented with a wifi-ethernet bridge so that a commercially available WiFi module can be used and interfaced with the microprocessor through its Ethernet interface.

3.3 – Gas sensors

There is a preference for sensors with low cost because the air quality monitoring station should be suitable for mass production. Also the sensors should have a small to medium size to be integrated in the station, making the station size appropriate to be placed at the roof of buses or cars. It is also desirable to have a fast response time for the sensors, because the air station has to do measurements while in motion, and is subject to a fast changing atmosphere.

It should be understood that it may not be possible to find available sensors that maximize all the refereed characteristics, but the choices made were having in mind all these concerns.

3.3.1 – CO and NO_2 sensor

The chosen sensors was the MICS-4514, these sensors are solid-state devices composed of sintered metal oxides which detect gas through an increase in electrical conductivity when reducing gases are absorbed on the sensor's surface. These sensors are both in the same SMD package, and have a small size. The MICS-4514 includes two sensor chips with independent heaters and independent sensitive layers. One sensor chip detects oxidizing gases (OX) and the other sensor detects reducing gases (RED). In order to be able to make exact measurements with MICS-4514 is necessary to take into account the effects that humidity and temperature have on the characteristic curve of the sensor resistance versus gas concentration (Fig. 3.2) [26]. The main characteristics of the sensors are presented in Tab. 3.2.

Tab. 3.2 – Characteristics of the MICS-4514 NO_2 and CO gas sensor.

Sensor characteristics	**Typical value (real values vary in the range [min,max])**
Heating power (P_H)	76mW/43mW (RED sensor/OX sensor)
Heating Voltage (V_H)	2.4V/1.7V (RED sensor/OX sensor)
Heating resistance at nominal power (R_H)	74Ω/66Ω (RED sensor/OX sensor)
CO detection range (F_S)	[1ppm;1000ppm]
CO sensor (RED) sensing resistance in air (R_o)	[100kΩ;1500kΩ]
NO_2 detection range (F_S)	[0.05ppm; 5ppm]
NO_2 sensor (OX) sensing resistance in air (R_o)	[0.8kΩ; 20kΩ]

a) **b)**

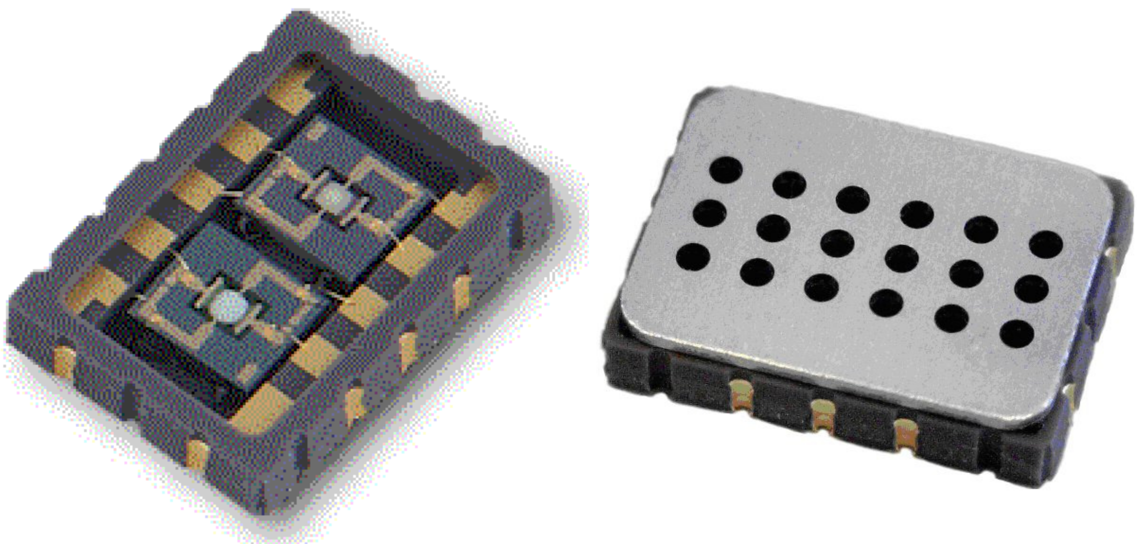

Fig. 3.2 – NO_2 and CO gas sensor, MICS-4514, a) picture is the inside view, the cover of the sensor was removed for the photo but is a fixed part of the sensor, b) picture is the normal view of the sensor.

3.3.2 – O_3 sensor

The chosen sensor was the MICS-2611, the sensor is a solid-state device composed of sintered metal oxides which detect gas through an increase in electrical conductivity when ozone is adsorbed on the sensor's surface. In order to be able to make exact measurements with MICS-2611 is necessary to take into account the effects that humidity and temperature make on the characteristic curve of the sensor resistance versus gas concentration (Fig. 3.3) [25].

Tab. 3.3 – Characteristics of the MICS-2611 O_3 gas sensor.

Sensor characteristics	**Typical value(real values vary in the range [min,max])**
Heating power (P_H)	80mW
Heating Voltage (V_H)	2.35V
Heating resistance (R_H)	68Ω
O_3 detection range (F_S)	[10ppb;1000ppb]
O_3 sensor sensing resistance in air (R_o)	[3kΩ; 60kΩ]
Sensitivity factor (S_R)	[1.5; 4]

Fig. 3.3 – O_3 gas sensor, MICS-2611.

3.3.3 – SO_2 sensor

The chosen sensor is from Alphasense and is an electrochemical cells that operate in the amperometric mode. That is, they generate a current that is proportional to the fractional volume of the toxic gas, in this case SO_2. The different models of the Alphasense gas sensors are very similar, they differ in the electrochemical reaction that occurs inside the sensor according to the gas the sensor should be sensitive. The interior of the sensor is made up of 3 electrodes. All the electrodes have an identical composition, and the electrodes are stacked in parallel inside the sensor. The cell electrolyte provides ionic electrical contact between the electrodes, usually with the aid of hydrophilic separators to allow capillary transport of the electrolyte which is usually sulfuric acid (Fig. 3.4). A potentiostatic circuit should maintain the potential of the working electrode at a fixed value with respect to the reference electrode potential. The working electrode is the surface where the electrochemical oxidation (CO, H_2S, NO, SO_2) or reduction (NO_2,Cl_2) occurs. The counter electrode balances the reaction of the working electrode – if the working electrode oxidizes the gas, then the counter electrode must reduce some other molecule to generate an equivalent current, in the opposite sense.

This electrode is exposed to the outside air and hence is directly exposed to all gases in the air including the gas to be measured. Therefore this electrode may be poisoned if exposed to certain gases that either adsorb onto the catalyst (e.g. acetylene onto CO sensors), or react, creating by-products which inhibit the catalyst (e.g. NO_2 or aromatics onto H_2S sensors). This is the same problem as poisoning in fuel cells and car catalytic converters [27],[28].

Electrode reactions for the SO_2 Alphasense sensor:

Working electrode reaction:	$SO_3 + 2H^+ + 2e^- \rightleftarrows SO_2 + H_2O$	E=+0.35V
Counter electrode reaction:	$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightleftarrows H_2O$	E=+1.25V
Overall sensor reaction:	$SO_3 \rightleftarrows SO_2 + \frac{1}{2}O_2$	E=–0.90V

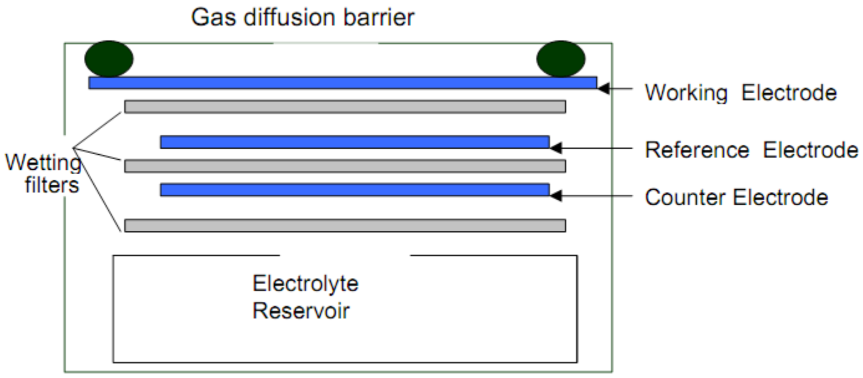

Fig. 3.4 – Representation of the Alphasense electrochemical gas sensors [28].

When operating in the transport limited current plateau the measured current (I_L) should be linearly dependent on the concentration or fractional volume of the toxic gas (C_T) in the external environment, k is a proportionality constant: $I_L=kC_T$. (3.1)

The sensor for SO_2 is used mounted on a board also manufactured by Alphasense that is called Analogue transmitter board. This board places an adequate voltage on the sensor pins and amplifies the sensor current that is proportional to the gas concentration, the transmitter board has two potentiometers that make possible to adjust the sensor current in clean atmosphere and the gain of the current amplification made on the board (Fig. 3.5).

a) b)

Fig. 3.5 – Picture a) is the Alphasense SO_2 gas sensor, Picture b) is the analogue transmitter board with a sensor mounted on it.

3.3.4 – CO_2 sensor

Alphasense IRC-A1 sensors use the principle of Non-Dispersive Infra-Red (NDIR) to determine gas concentration. Each sensor consists of an infrared source, optical cavity, dual channel detector and internal thermistor (Fig. 3.6). Gas diffuses into the optical cavity. Light from the infrared source passes through the optical cavity where it interacts with the gas before impinging on the detector. The dual channel detector is comprised of an active channel and a reference channel. The active channel is fitted with a filter such that the only light with a wavelength that corresponds to an absorption band of the target gas is allowed to pass through. If the target gas is present in the optical cavity the intensity of light passing through the filter and hitting the active channel decreases. The reference channel of the detector is fitted with a filter that only allows wavelengths of light where there are no absorption bands to pass through. The use of a reference channel allows variations in the light intensity to be compensated for. The detectors used are highly sensitive to the ambient temperature and so it is necessary to constantly monitor the temperature and compensate the output. The internal thermistor is used for this purpose [29], [30].

Fig. 3.6 – NDIR IRC-A1 Alphasense CO_2 gas sensor.

3.4 – Humidity and temperature sensor

Initially Sensirion SHT75 humidity and temperature sensor was used. The SHT75 uses a specific protocol that is similar to I2C, but has some differences that make necessary some procedures on the I2C bus that don't match normal I2C operation. As project evolved this differences in the protocol turned into some problems because of the fact that the microprocessor used is constantly running an operating system (Linux for embedded systems), so all the communications through the I2C bus should be made by the I2C Linux driver. Of course for SHT75 the I2C driver is not enough, and an external control (made by GPIO pins) must be made to match the sensor protocol. But as all the user programs in Linux, run through threads, that can be interrupted or continued by the thread scheduling, this makes difficult to guaranty the timings between changes made by the GPIO on I2C bus and the changes made by the I2C driver on the I2C bus.

The same company that manufactures SHT75, has recently developed (lunched on December 2010) a similar sensor,named SHT25 (Fig. 3.7). That uses a standard I2C protocol, and has a price lower than SHT75. It was thus decided to use this new sensor. Tab. 3.4 presents it's main specifications.

Tab. 3.4 – Characteristics of the Sensirion's SHT25 relative humidity and temperature sensor.

Sensor characteristics	**Typical value (real values vary in the range [min,max])**
Humidity Resolution	0.04 %RH (12bit)
Humidity Accuracy	±1.8 %RH
Humidity Repeatability	±0.1 %RH
Humidity Response Time (tau 63%, Time for reaching 63% of a step function, valid at 25℃ and 1m/s airflow.)	8s
Humidity Operating Range	[0%RH,100%RH]
Humidity Long Term Drift	<0.5 %RH/year
Temperature Resolution	0.01 ºC (14bit)
Temperature Accuracy	±0.2 ºC
Temperature Repeatability	±0.1 ºC
Temperature Operating Range	[-40 ºC,125 ºC]
Temperature Response time (tau 63%, Time for reaching 63% of a step function, valid at 25℃ and 1m/s airflow.)	17 s
Temperature Long Term Drift	<0.04 ºC/year

Fig. 3.7 – Picture of SHT25 sensor.

3.5 – The Analog to Digital Converter (ADC)

The main board is provided with a 10-bit Analog-to-Digital Converter (ADC) based on a Successive Approximation Register (SAR). It makes possible the conversion of up to 4 voltages, because it integrates a 4-to-1 analog multiplexer. This ADC can be interfaced through the Linux system functions when the ADC driver is loaded on the system. The interface is based on the file /dev/adc that is created when the ADC driver is loaded. To be able to work whit the ADC on a program we should use the system function “open()” to get a file descriptor to the ADC file. The ADC can be configured with the system function “ioctl()” using the file descriptor to make a reference to the ADC. The ADC can be read using system function “read()”. I tried to work with ADC on the C10/3 board that was given to me, my experiences where based on the instructions present on the Telit “GE863-PRO3 Linux Software User Guide” that explained how to use the ADC, the manual didn't had any complete sample code that could be used to check if the ADC is working properly, It was also searched support on how to use the ADC on the Round Solutions forum and on the internet, but the support received by those means wasn't helpful to solve the difficulties. For reasons that I wasn't able to fully understand every time the function “read()” was called to read values from the ADC an error was generated, the error message given by the system was “errno: Operation not permitted”.

Because of the problems with the GE863-PRO integrated ADC that couldn't be solved, it was chosen to work with an external ADC that was interfaced with the GE863-PRO3 chip through the I2C bus. The ADC chosen was the ADS7828 from Texas Instruments. The ADS7828 is a single-supply, low-power, 12-bit data acquisition device that features a serial I2C interface and an 8-channel multiplexer. The Analog-to-Digital (A/D) converter features a sample-and-hold amplifier and internal, asynchronous clock. The ADS7828 has a sample rate of 50 ksamples/s , this sample rate is more than enough to acquire the samples from the sensors. The voltage supply of the ADS7828 works on the range 2.7 V to 5 V and has an internal 2.5 V voltage reference (Fig. 3.8).

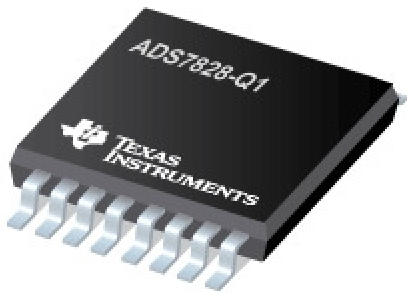

Fig. 3.8 – Picture of ADS7828, ADC.

3.6 – The Ethernet interface

The selected hardware for the system core was the C10/3, which incorporates the chip GE863-PRO3 from Telit, this chip has an Ethernet controller that supports compatible with the 10Mbit/s and 100Mbit/s IEEE 802.3 standard. The Ethernet controller is made to work with a PHY transceiver through the Media Independent Interface (MII).

Round Solutions (manufacturer of C10/3) sells an Ethernet interface specially designed for their development board, the STK-S4, the price of the Ethernet interface made by Round Solutions is 130 €, so obviously isn't a option to buy the Ethernet interface from Round Solutions, so a clone of the Ethernet interface was developed, the price of the components for the Ethernet interface is about 10 €. This clone has an Ethernet PHY transceiver, and a RJ45 port with integrated magnetics, it also incorporates 2 LEDs to display the activity on the Ethernet interface (Fig. 3.9).

a) **b)**

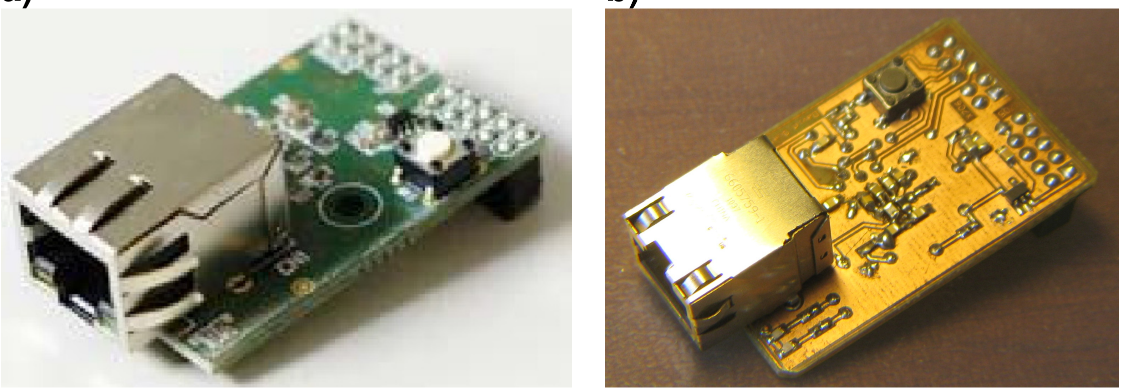

Fig. 3.9 – a) Ethernet adapter sold by Round Solutions, b) Clone developed by me of the Ethernet adapter.

3.7 – The Ethernet-wifi bridge

It is used an ethernet-wifi bridge to implement the wifi interface on the station. The selected hardware was the ASUS WL-330gE. The WL-330gE was selected because it's very configurable, it can work in 4 different modes: repeater, access point, Ethernet-wifi bridge, router. It was chosen also because of its small size, which is about what was available inside the box of the portable pollution measurement station. It is appropriate also because it allows the installation of the Open-WRT Linux firmware, allowing complete device customization and control if required by the project objectives (Fig. 3.10).

Fig. 3.10 – Router, Ethernet bridge, repeater, Access point, WL-330gE.

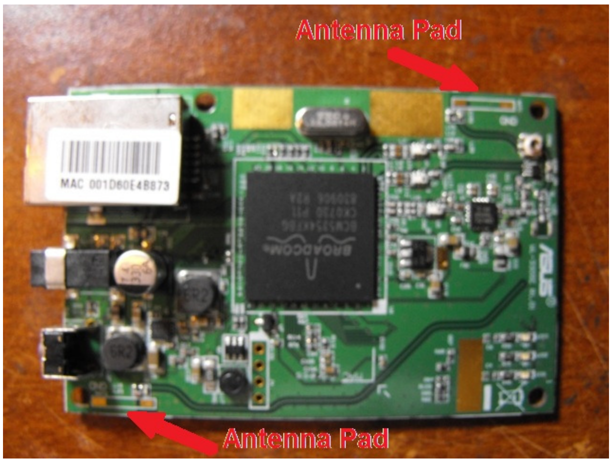

Fig. 3.11 – Inside view WL-330gE.

The WL-330gE has built in wifi antennas, but also has pads on the PCB available to solder 2 extra wifi antennas (Fig. 3.11). The WL-330gE is placed inside the box used for the station. The chosen box is made of aluminum, so it is expected a large signal attenuation if the built in antennas are used because they are placed inside a closed metal surface. So an external wifi antenna was used, and was connected to a cable that was soldered to one of the pads available (Fig. 3.12).

The WL-330gE has a supply voltage of +5 V, but the supply voltage of the station is 12 V, so a switched voltage converter was used to obtain 5 V from the 12 V. The voltage converter used is the TL2575-05, and it requires the additional components to work: 330 μH coil, 330 μF capacitor, 100 μF capacitor, a Schottky diode (Fig. 3.13).

It was experienced during the project development that when system boots up the Ethernet connection of the board doesn't gets always active. The Ethernet connection between the board and the wifi-bridge should be auto-configured always, but the experiments made show that it doesn't always happens. So to overcome this problem it was placed a relay in series with the power supply of the WL-330gE, the relay is controlled by one of the GPIO pins of the C10/3 (I used GPIO 93, this is PC29 pin), the relay used was TSC-112L3H and it was placed on the same board were the 12 V to 5 V voltage converter is. So by using this relay it is possible to reset the WL-330gE making another opportunity for the router to configure the Ethernet connection to the board. This is all done with a script that is run when the system starts up, and checks if a connection is available between the WL-330gE and the base board, if the connection is not available it restarts the router and checks again, it tries 4 times before failing, this is more than enough to assure the Ethernet connection is configured.

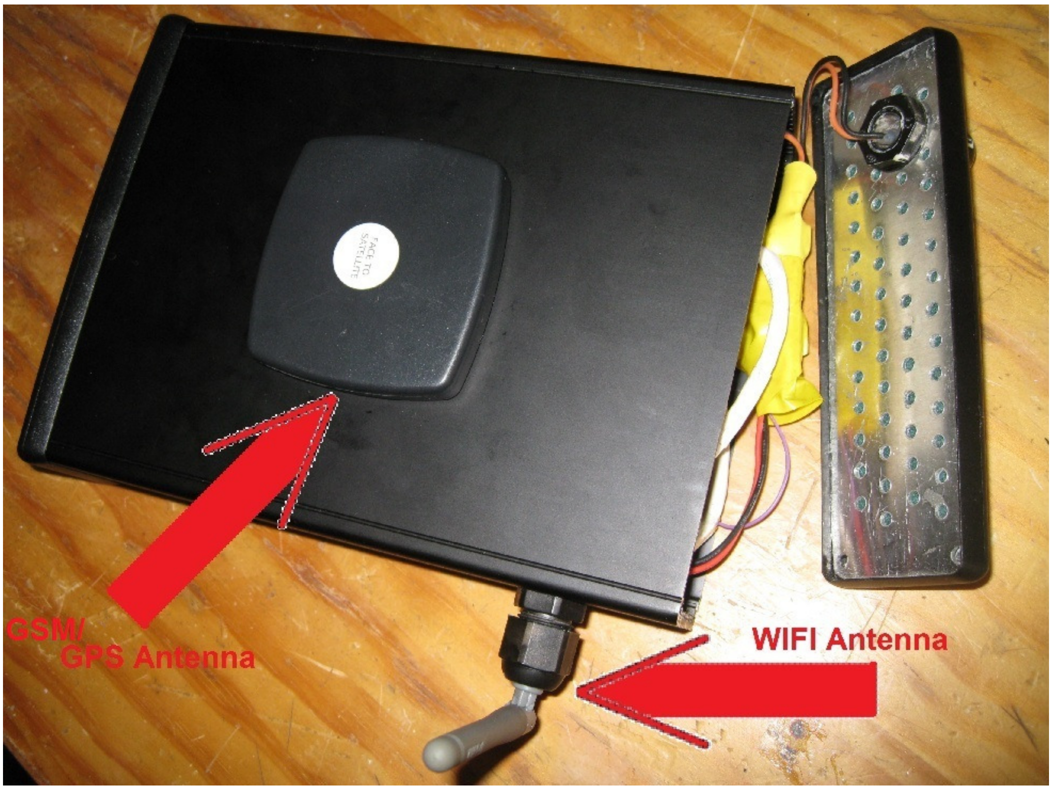

Fig. 3.12 – GPS and wifi antenna mounted on the station box.

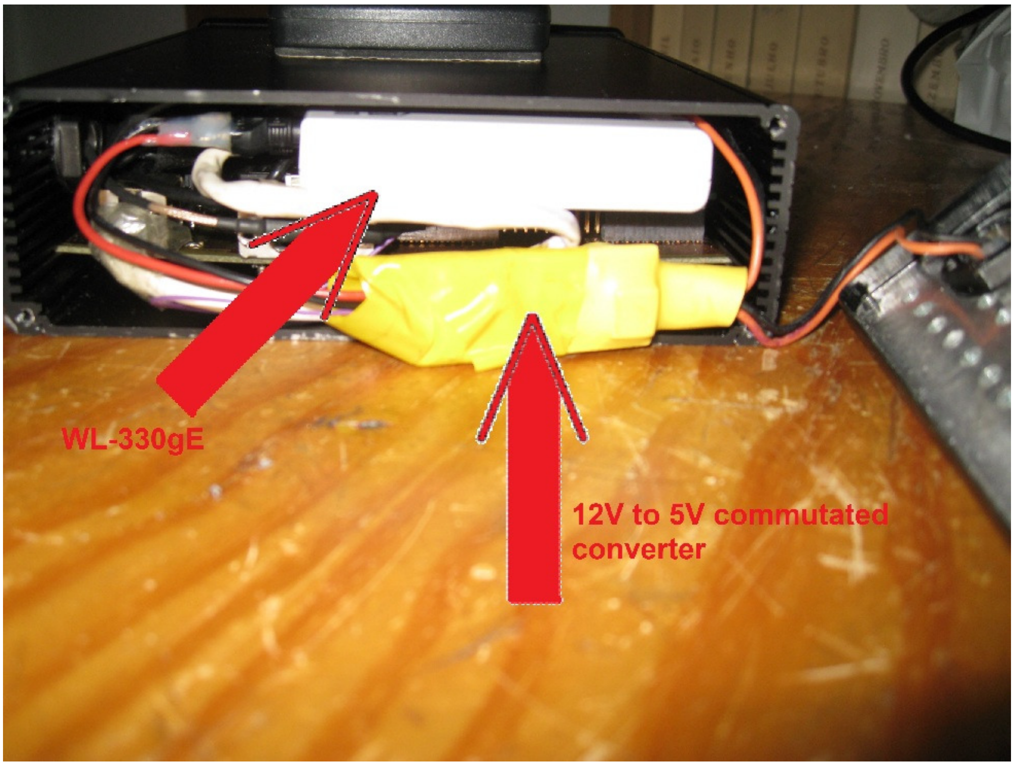

Fig. 3.13 – WL-330gE and the 12 V to 5 V converter placed inside the box of the station.

In order to be able to communicate with the pollution measurement station, the WL-330gE must be configured correctly. The default IP address of the WL-330gE is 192.168.1.220, and it has a HTTP interface that lets the user configure the device operation mode and the usual configurations for a router (Fig. 3.14, Fig. 3.15). The WL-330gE should be configured in Access Point mode, because in this mode the Ethernet port and the computers connected through WIFI are all in the same network (in Gateway mode the Ethernet ports must be connected to a WAN). In this mode the WL-330gE doesn't offers a DHCP server so the computers connected to the router should have their IP addresses configured for fixed IP address (Fig. 3.16).

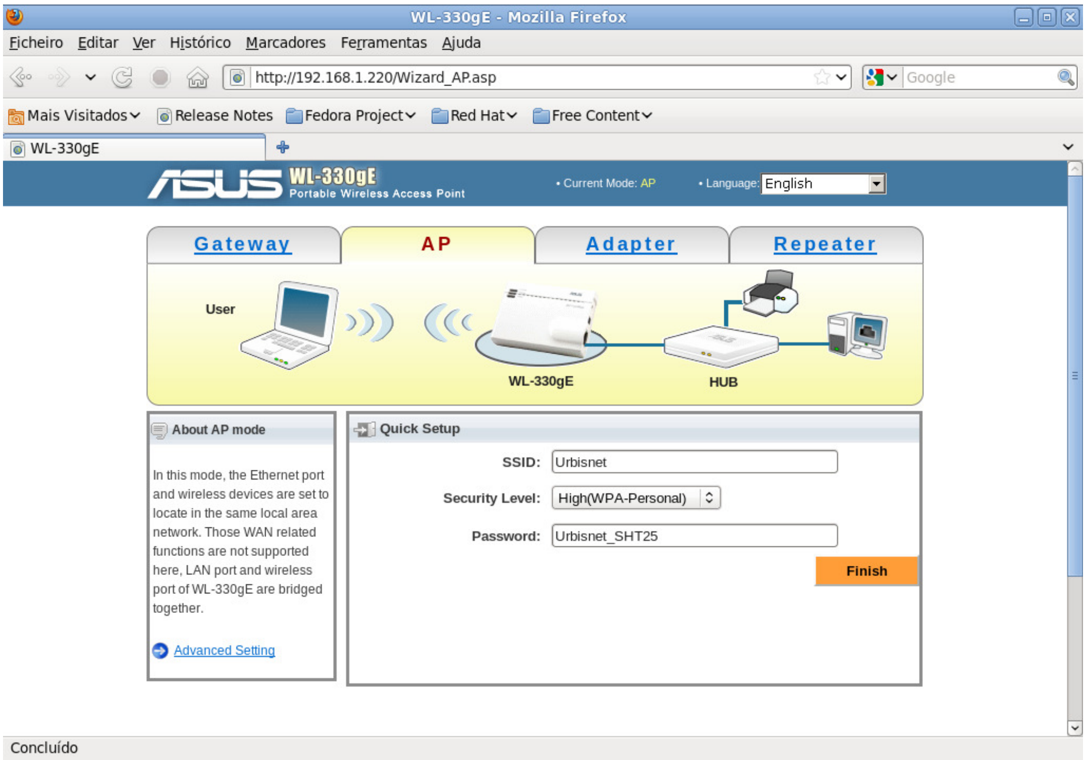

Fig. 3.14 – Configuration page of the WL-330gE.

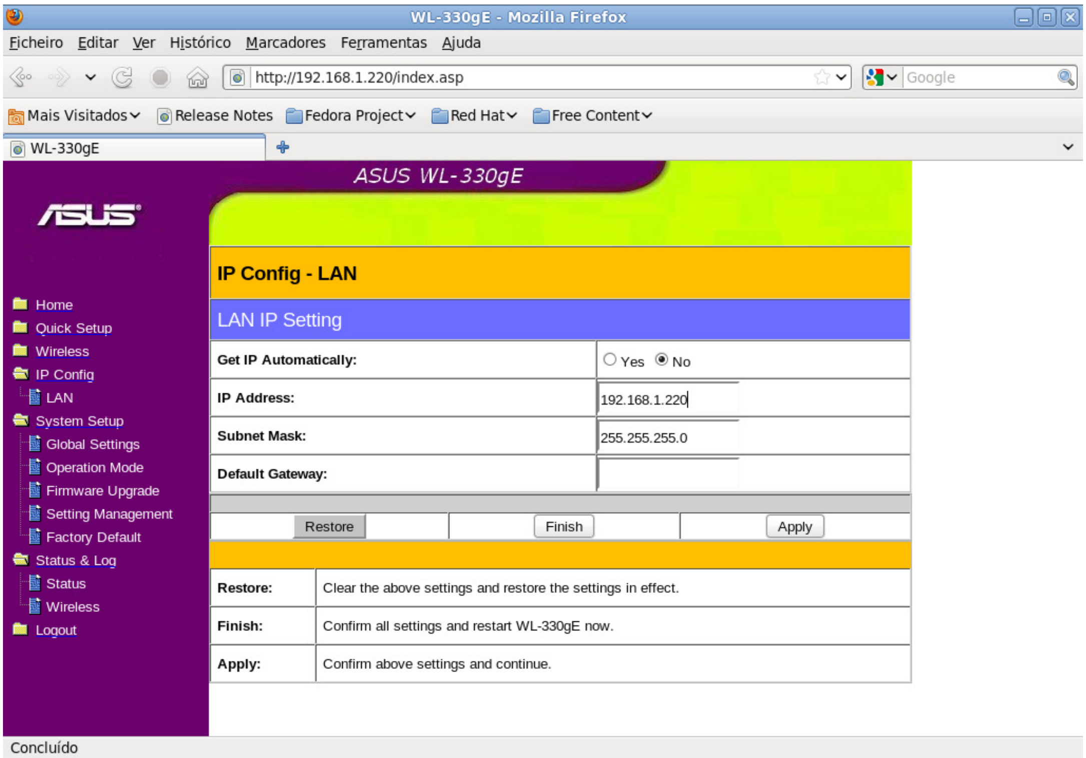

Fig. 3.15 – IP configuration of the WL-330gE.

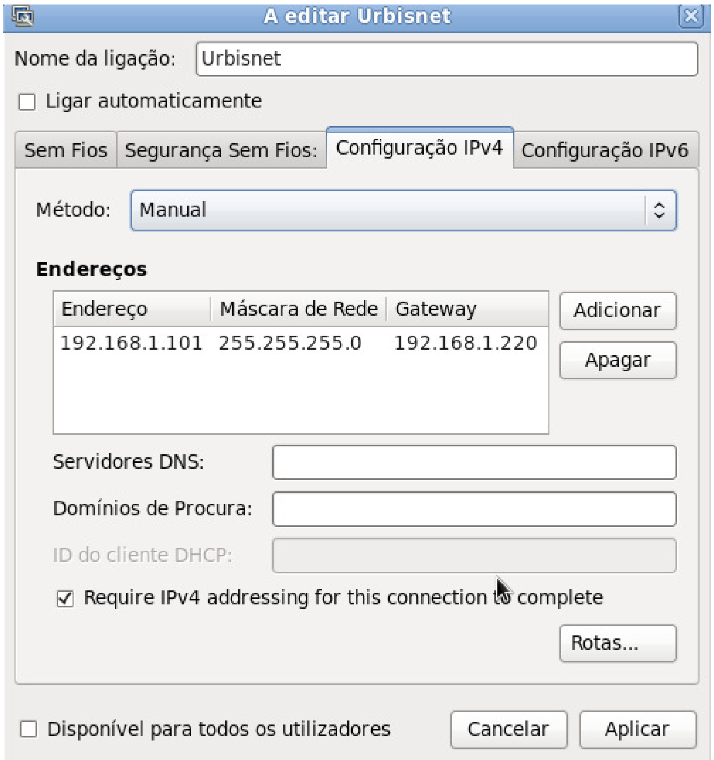

Fig. 3.16 – Configuration window of the IP address for the client computer in Linux.

3.8 – Electronic circuit design

The electronics was divided into two PCBs, main board and sensor board. The main board with a socket for the C10/3 board from Round Solutions, the SHT25 humidity and temperature sensor, voltage regulators for -3.3 V, -2.1 V, +2.85 V, +3.3 V, +4 V, +5 V, +8.08 V, the ADS7828 Analog to Digital converter, and a auto-start circuit to start the GSM module of the C10/3 when the power is switched on, an Ethernet interface and a serial port that gives access to the console of the Linux running in the ARM.

The 2nd board has gas sensors that can be connected to the primary board with a flat cable, the sensors included in this board are for CO_2, CO, NO_2, O_3, SO_2. The sensor board also includes the electronic circuits appropriate to make the sensors works and to extract a voltage that is proportional to the sensor output. This sensor board is connected to the main board with a flat cable making it easy to be replaced by a different board with different sensors.

The main board is projected to be powered by a 12 V DC voltage, in case a small swing is observed on the input voltage there should be no problem. It is important that the input voltage never drops below 10 V, as it was observed, in case that happens one of the circuits of the sensor board makes one of the sensors output above 4 V, and that voltage placed on one input of the ADC makes the ADC read on all channels it's maximum voltage that is 2.5 V.

There is also a small board that has a switching voltage converter. That is used to convert the input voltage of the station from 12 V to 5 V to power the WIFI router. This board also includes a relay that can disconnect the power from the WIFI router, the relay is controlled by one of the pins of the GPIO of C10/3, the relay is connected to C10/3 through a wire (Fig. 3.17).

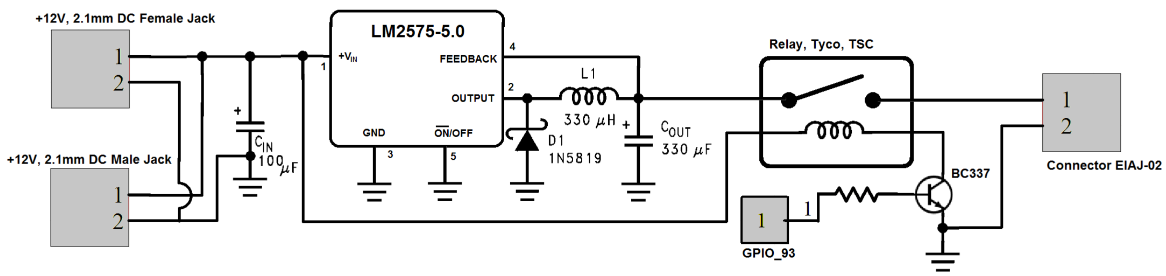

Fig. 3.17 – Schematic of the 12V to 5V converter board.

In the main board the +4 V voltage regulator, is the one that feeds the C10/3 and has a large heat dissipation, so it needs a large heat sink, I built a custom heat sink. This heat sink is attached to the voltage regulator with a bolt and a thin thermal pad to assure electrical insulation and good heat conductivity (Fig. 3.18, Fig. 3.19).

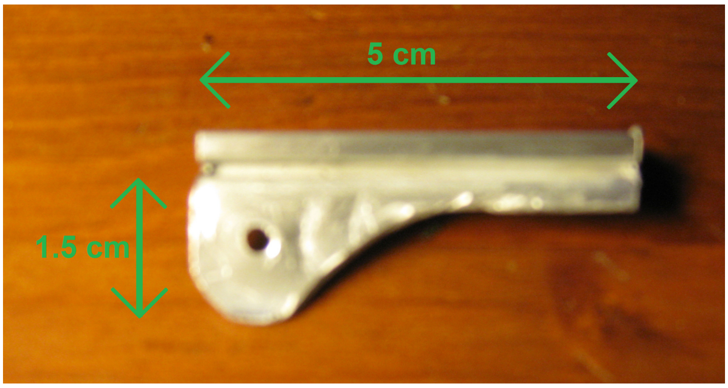

Fig. 3.18 – Dimensions of the heat sink for the 4 V voltage regulator.

Fig. 3.19 – Heat sink for the 4 V voltage regulator.

The electrical circuits to work and extract the signal of the CO, NO_2, O_3 gas sensors are just 2 resistors per sensor, one resistor (R_H) to control the power used on the sensor heating, and another resistor (R_S) to obtain a voltage that is proportional to the sensor resistance, the sensor resistance changes when the gas concentration changes (Fig. 3.20). The manufacturer of the sensors doesn't specify the value for the sensor resistance, it only specifies a somehow large interval for the value of the sensor resistance. It is up to the designer/user to decide what value to use with each sensor, in accordance with the desired sensor measurement range and the experimental tests (Fig. 3.21).

The values for R_H were 82 Ω for the CO sensor and 135 Ω for the NO_2 sensor and are specified on the sensor datasheet. The values for the R_S were determined experimentally, at the moment of the sensor calibration, the value for the CO sensor was set on 24 kΩ and the value for the NO_2 sensor was set on 10 kΩ.

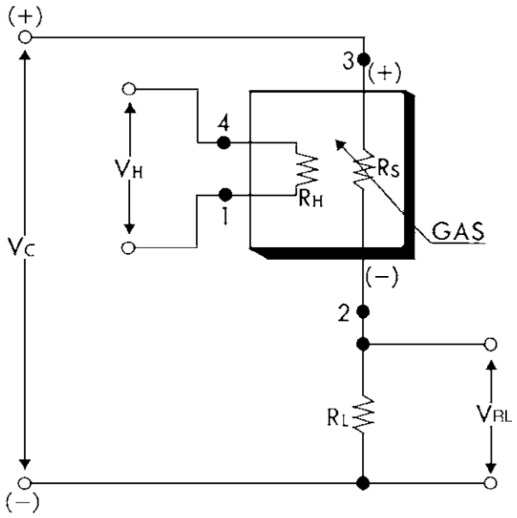

Fig. 3.20 – Electrical model for the Metal Oxide Semiconductor gas sensor.

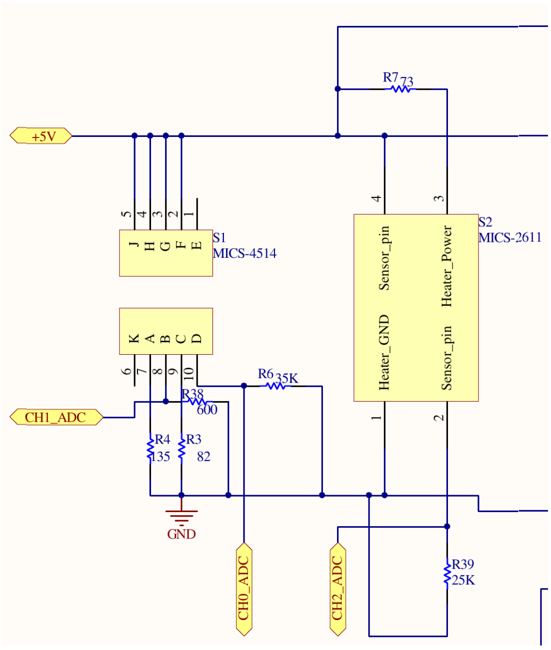

Fig. 3.21 – Circuits used with the MICS-4514 CO/NO_2, MICS-2611 O_3.

The electrical circuits used to operate and extract the signal of the NDIR IRC-A1 CO_2 gas sensor were based on the schematics provided by the sensor manufacturer, and modifications were made based on the experiments made with the sensor and the circuits, to obtain the best possible sensor output signal. The schematic given by the manufacturer is: the sensor lamps are stimulated by a 2 Hz signal, and after the sensor detectors the signal is filtered to remove the DC component and the signal is then amplified (Fig. 3.22).

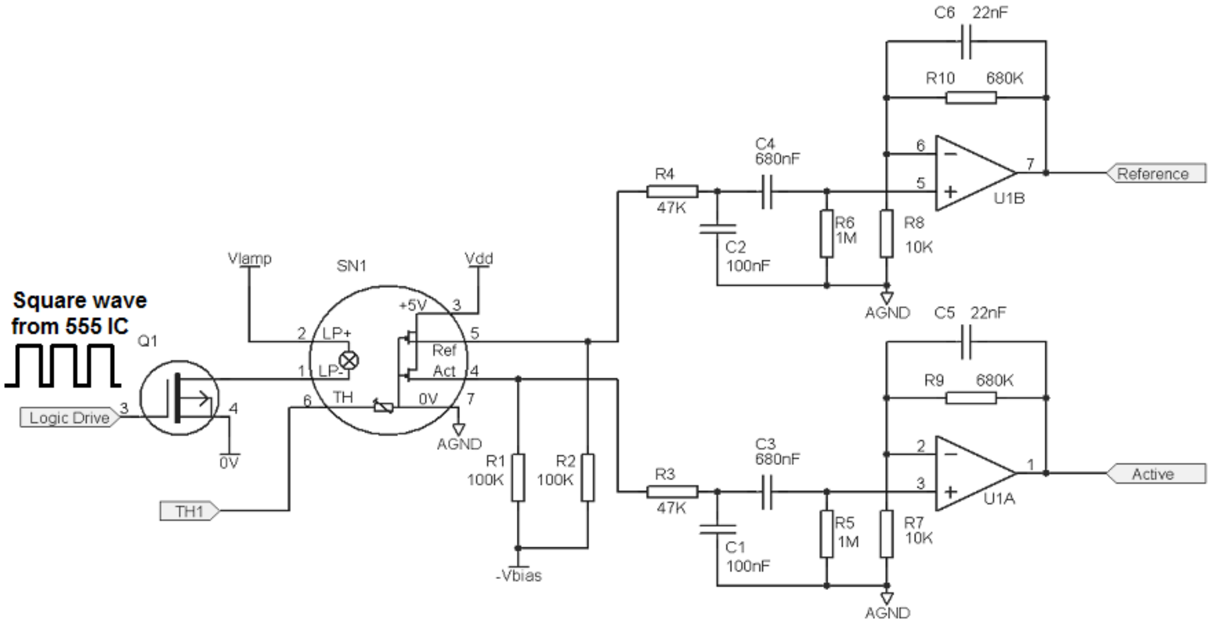

Fig. 3.22 – Circuits used to stimulate and extract the output of the NDIR IRC-A1 CO_2 gas sensor.

In the early tests made with the NDIR IRC-A1 with the circuit mounted on a breadboard, it was found that the ground node was affected by noise that was then amplified by the signal processing circuit, and the amplified noise dominated the output of the circuit. To remove the noise on the ground node, it were reinforced the connections between the several parts of the breadboard that were the ground node with extra wires. When the NDIR IRC-A1 sensor is mounted on a PCB this problem doesn't happen because of the ground plane of the PCB.

The NDIR IRC-A1 CO_2 sensor works with alternating signals but the effects of any gas present on the atmosphere only affect the signal amplitude, so a signal rectifier and a filter were used to obtain a DC voltage proportional to the signal amplitude (Fig. 3.23).

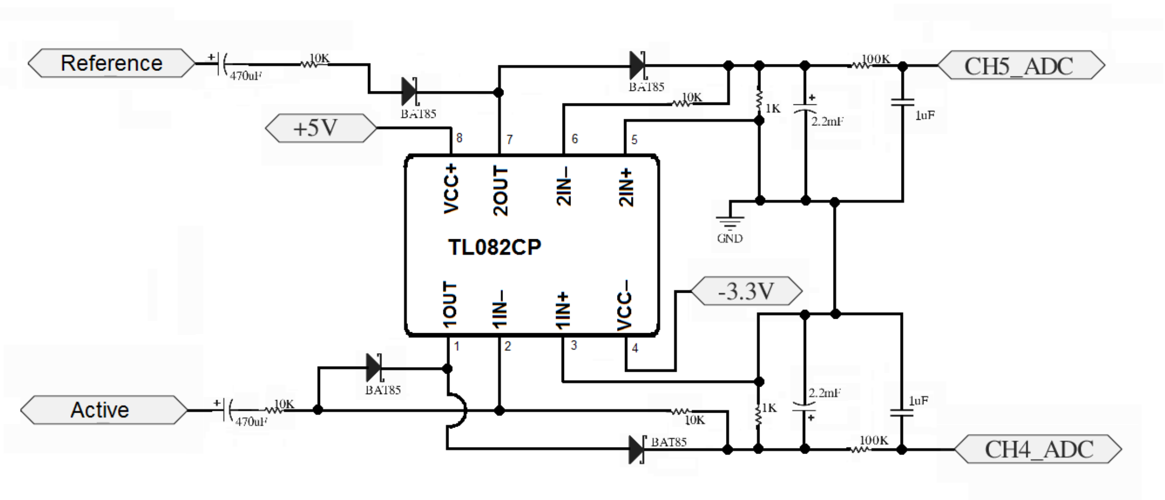

Fig. 3.23 – Circuits used to obtain the peak value of the IRC-A1 signal output.

The output of the SO_2 gas sensor (that is not appropriate to measure the target range of the gas concentrations) is a DC current with an intensity proportional to the concentration of the gas to be measured. The SO_2 gas sensor mounted on the analogue transmitter board only has 2 terminals (the VCC and GND), it should be powered by a voltage higher than 7.5 V. So a small resistance was used to obtain a voltage proportional to the sensor current, but the resistance used was small enough to practically don't change the supply voltage to the sensor.

As the SO_2 gas sensor has an output current in the range [4 mA (clean air); 20 mA (saturated with SO_2)], and the used supply voltage was 8.083V, this means that a maximum voltage drop of 8.083 V−7.5 V = 0.5083 V should be present on the resistor. So V_R< 0.5083 V <=> R_S< 0.5083V/0.02 A <=> R_S < 25.42 Ω .

A 10 Ω resistor was used to convert the output current to voltage, and an instrumentation amplifier was used to amplify its value enough to be read by an ADC (Fig. 3.24).

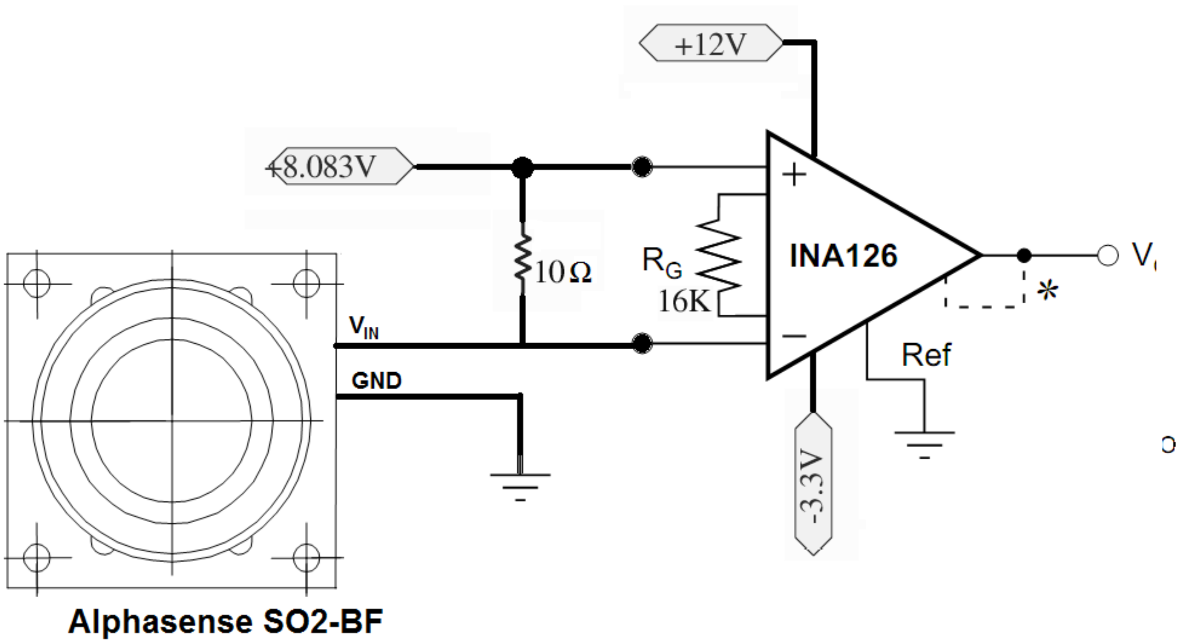

Fig. 3.24 – Electronics circuit for the SO2-BF gas sensor.

3.9 – The printed circuit board design

The printed circuit boards (PCBs) for the Urbisnet station were projected having in mind the objectives of the work. The chosen enclosure has several longitudinal slots that allow the placement of the PCBs, suspended in a way similar to shelfs. The PCBs were designed from the start having in mind their dimensions so that they would fit the box in perfection.

The components and circuits were displaced on the PCB with the concern to minimize the length of the tracks and the use of VIA to solve the track intersections. The plugs and connectors were placed on the PCB with the concern to be on the best position to be accessed by the user and to facilitate the connections between the components.

Tree PCBs were designed, these were interconnected and connected to the devices inside the enclosure using various different cables. It is advantageous the distribution of the hardware on 3 PCBs, making the Urbisnet Station more modular. This can be advantageous when replacing some malfunction part and when a part of the hardware is intended to be modified it allows that modifications are made saving most of the work already done. Also the fact that the hardware is modular, allows the use of the PCBs that are already projected to, for example, a different project were one of the PCBs could be valuable.

The hardware on the PCBs was in part composed by SMD components and in part by through-hole components. This is so because several circuits were extracted from the schematics and hardware that was produced by Round Solutions that was relevant to the project, and this hardware was made with SMD components so there was no reason to change. The hardware that was specific and designed to the project was implemented with through-hole components because space was not an important constraint.

3.10 – The station assembly

An appropriate box for the station was chosen, the box should protect the hardware that is inside from the water of the rain, but at the same time allow the outside air to flow through the box, so that the sensors can detect the gases present on the atmosphere, and make readings of humidity and temperature. The ventilation may also be important in days were the station is subjected to long hours under the exposure of the sun light that can cause an overheating of the station. So the chosen box was a box sold at the Farnell website, that has the appropriate dimensions, and that had also an adequate price 36 €. The box has the dimensions 22 cm x 16,5 cm x 5,15 cm, is made of Aluminum, inside the box there are longitudinal holders on the sides, that allow for the PCBs to be inserted on the box an stay placed like if they were shelves. The box also comes with two apertures, on front and back, these apertures come with lids that make the box a closed space, the lids are supported by 4 bolts.

As one of the requirements is that the box must allow the air to flow through the box, these lids had to be replaced by lids that were specially developed and built. It is able to block the entrance of the rain to the inside space of the box. This system for the lids is composed of 2 lids for each entrance with the ventilation holes misaligned, and with an sponge to block water droplets and large particles of dust (Fig. 3.25, Fig. 3.26, Fig. 3.27).

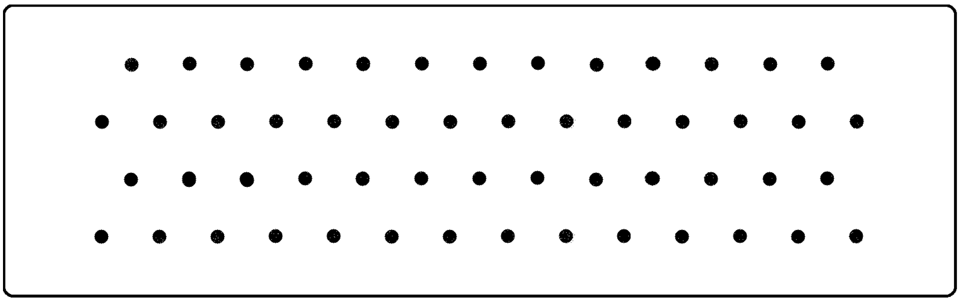

Fig. 3.25 – Drawing of one of the lids, the dots represent the holes but that real holes diameter is greater that on the drawing.

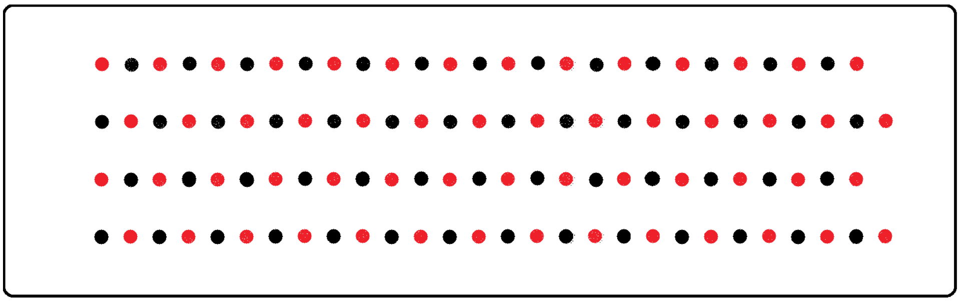

Fig. 3.26 – Drawing of 2 overlapping lids for covering only one aperture, as you can see the holes on the outside lid are misaligned with the holes of the inside lid.

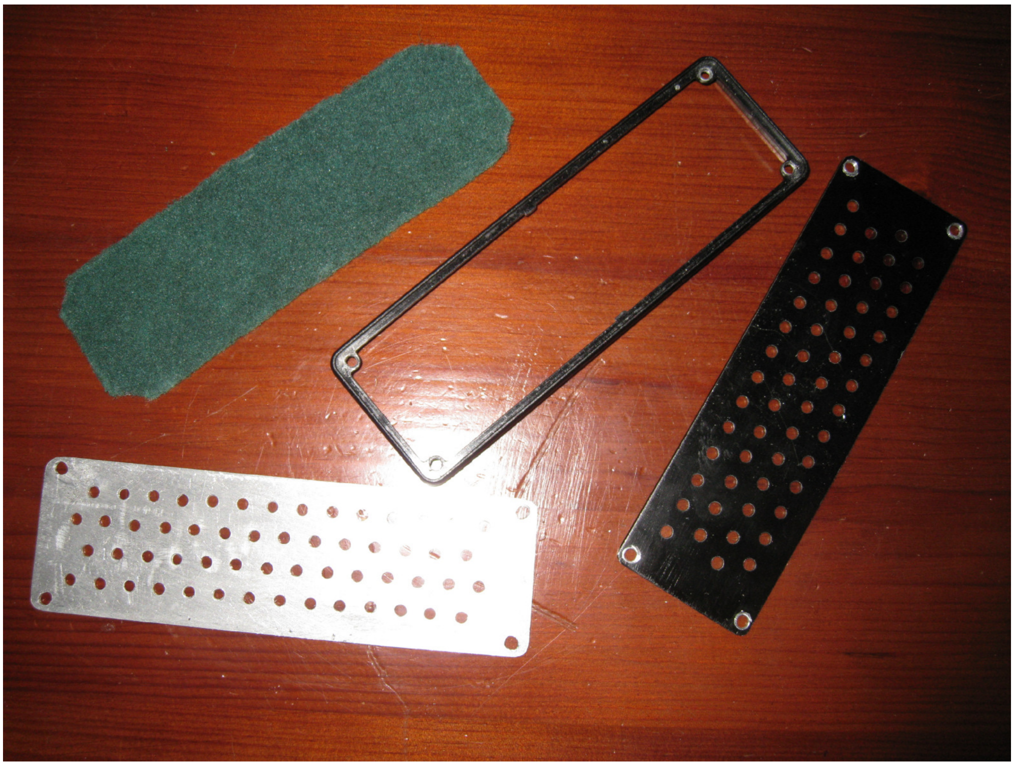

Fig. 3.27 – The lids and the green sponge.

This design allows for the entrance of air and protects from the rain that falls on the top of the box. To get a good protection from the rain the user should cover the small gap that exists between the lid and the box with Teflon tape (the type of tape used in plumbing to prevent leaks in the pipes junctions), and then screw the bolts to tighten the lids to the box. The Teflon tape placed on the edges of the box should have at least 3 layers to have some volume making the box have a good insulation against the rain, as can be seen on Fig. 3.28.

Fig. 3.28 – Box with the insulating Teflon tape.

The Urbisnet station hardware was fully assembled and mounted inside the selected enclosure, the interconnections between the several components were made with the the appropriate cables and connectors.

A view of the station hardware and the mounted station is on the images 3.29, 3.30, 3.31.

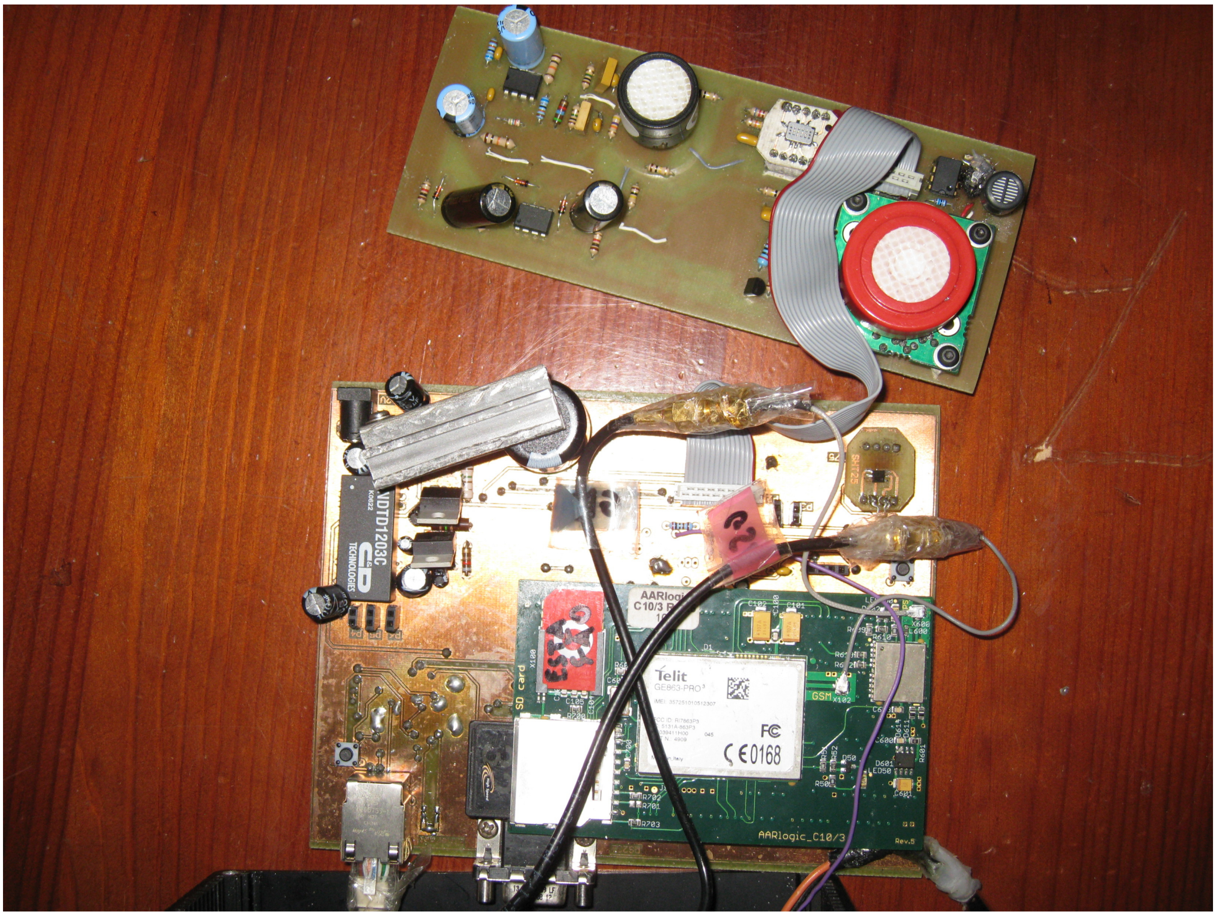

Fig. 3.29 – The main board and the sensor board.

Fig. 3.30 – Urbisnet Station, side view.

Fig. 3.31 – Urbisnet Station, top view.

4 – The software interface

The station can communicate by WIFI (IEEE 802.11) and GSM SMS messages, with these communications the station can interface with a PC, a server that receives communications from several Stations, or with a network of similar stations and routers that sends data to a central server.

The implemented software is aimed to make the data transmission directly to a PC. The software for the PC has the ability to show the received measurements from the Urbisnet Station, and to send new configurations for the Urbisnet station. When the program starts is shown a window asking the user to select the type of communications, it can be WIFI or GSM.

In case the communication is being made with WIFI the computer must have installed a WIFI network interface, the user then must connect to the WIFI network broadcasted by the station. After being connect to the network the user can open a telnet connection on port 23, to the station being able to control the station directly by the Linux console of the Urbisnet Station. In the program for the Urbisnet the user should specify the IP address of the station, the port used to upload the station configurations and to download the data obtained by the sensors. The program Urbisnet for the PC is made to work with a program that should be running on the station called Urbisnet_Station. The Urbisnet_Station program is always listening for new configurations sent by the PC, and acts accordingly to the configurations.

In case the communications is being made with GSM the computer must have a serial port (or a serial to USB adapter), this serial port should be connected to a GSM board that can be interfaced with AT commands, allowing this way to send configurations and to receive data from the sensors. The Urbisnet_Station program that runs in the station is configured by the PC to work with GSM or WIFI communications. The user can check the credit of the SIM inserted on the GSM interface for the PC, connected by the serial port, by sending a CUSD command, which can be typed of the text box CUSD code, and clicking the Send CUSD button. The user can check the credit of the SIM inserted on the C10/3 by opening a telnet connection to the Urbisnet_Station, and then executing the program Send_CUSD, with the appropriate SD command.

Fig. 4.1 – Startup window for the selection of the type of communications (WIFI, GSM).

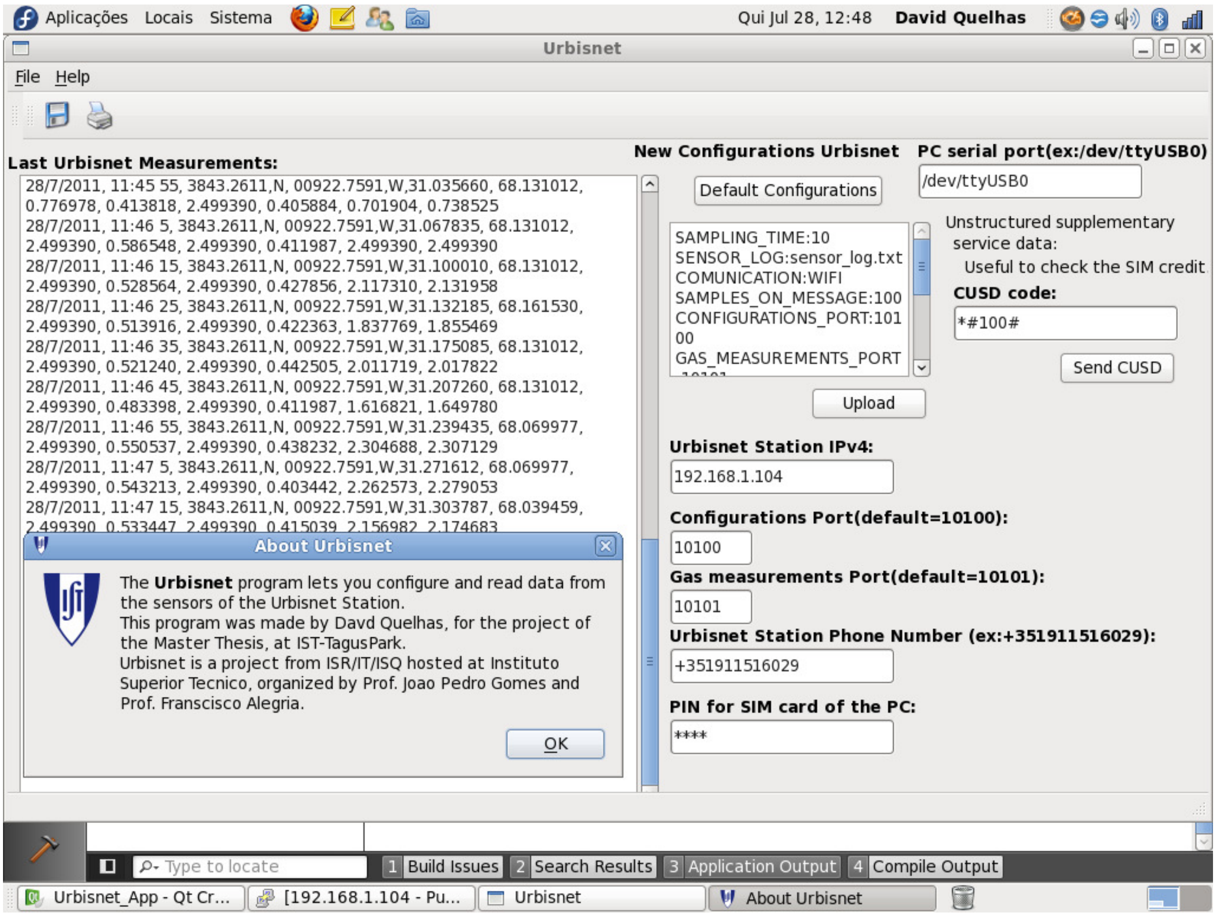

Fig. 4.2 – Main window of the Urbisnet program on the PC.

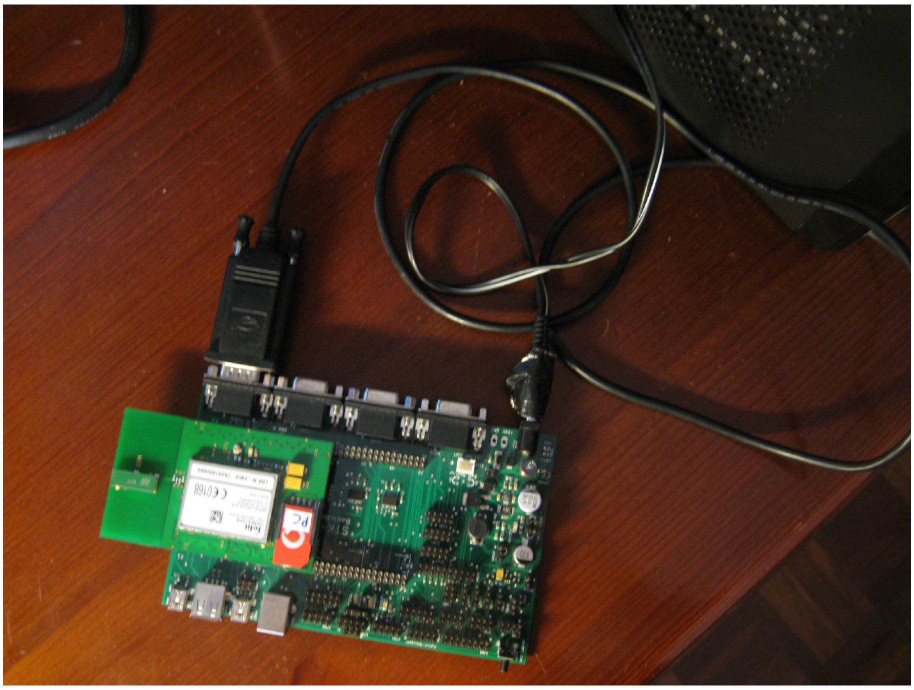

Fig. 4.3 – GSM board to interface with the PC, the picture is of GE863-GPS.

The Urbisnet program on the PC has the ability to send a configurations file to the Urbisnet Station, this file is called config_Urbisnet_Station.txt, this file is located on the Urbisnet Station on the same folder where is the program Urbisnet_Station. Every time the Urbisnet_Station program is started on the station, this file is read and the Urbisnet_Station program will operate in accordance with those configurations. This is an example of such file:

```
### Urbisnet configuration file ###
SAMPLING_TIME:10
SENSOR_LOG:sensor_log.txt
COMUNICATION:WIFI
SAMPLES_ON_MESSAGE:6
CONFIGURATIONS_PORT:10100
GAS_MEASUREMENTS_PORT:10101
PC_SERVER_IPv4:192.168.1.101
PC_SERVER_PHONE:+351911516109
STATION_SIM_PIN:2038
SMS_CENTER:+351911616161
```

The sampling_time is the time interval, between each set of readings the station makes from the sensors.

The sensor_log is a path to the text file where the program should save the samples from the sensors. The communications is a parameter that can be WIFI or GSM , the station transmits the data and listens to configuration with the interface that is selected on the configurations file.

The samples_on_message in case of WIFI communications is the number of samples (a sample is a set of readings from all the sensors plus time, date, and geographical location) the station sends each time to the PC. This is, the Urbisnet Station is continuously reading samples, and when the number of not transmitted samples reaches the samples_on_message value, then it connects to the PC and sends the most recent samples to the PC. In case of GSM communications, due to the limited character number (140 characters) of SMS messages, then the station sends one sample on each SMS message, but sends the messages in a burst, and the samples_on_message is the number of messages sent in a burst.

The configurations_port is the TCP port used to listen to new configurations when the Urbisnet Station is working in WIFI mode.

The gas_measurements_port is the port the Urbisnet Station should connect to the PC to send the most recent samples each time when is working in TCP mode.

The pc_server_IPv4 is the IPv4 network address the Urbisnet Station should connect to send the samples to the PC.

The pc_server_phone is the phone number the Urbisnet_Station should send the messages to when is working in GSM mode.

The station_SIM_PIN is the PIN number for the SIM card that is placed on the Urbisnet Station.

The SMS_center is the phone number for the center of SMS messages of the mobile phone operator of the SIM card that is used on the Urbisnet Station.

There are 3 startup scripts that are run automatically each time the Urbisnet_Station is powered on, these scripts are called S02,S03,S04. They load the Ethernet driver and I2C driver, configure the MAC address and the IP address. They also test the connection to the WIFI router, and in case the station processor can't communicate with the router, they reset the router so that the Ethernet connection can reconfigure again. They do this through a relay, which is controlled by the GPIO93. The script acts on this pin through a specific program wrote by me, this program is called GPIO_GE863-PRO, it receives as parameters the number of the pin to be changed and its value.

Scripts were made to be able to upload and download data from the Urbisnet_Station. The transfer of data is done by a ftp connection, so a ftp server should be installed on the PC, it was used the vsftp server that is easy and free to install. To be able to upload files to the station the user must first copy the files to the folder /var/ftp/pub so they can be accessed by the Urbisnet Station.

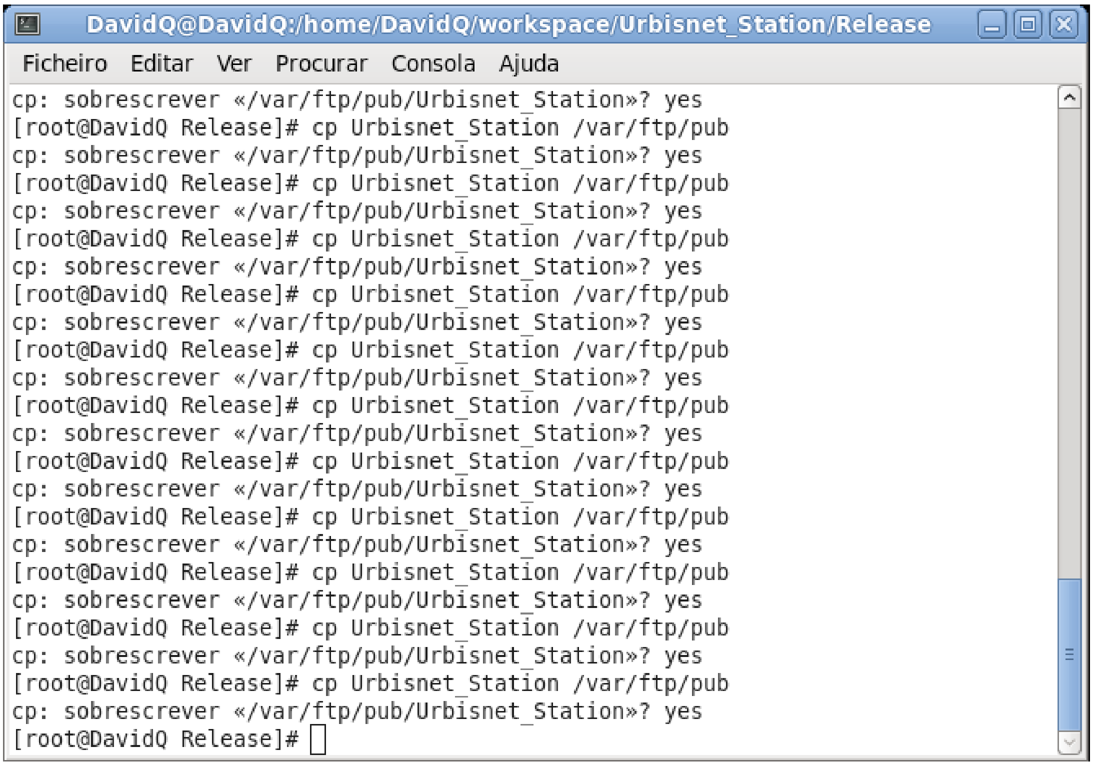

Fig. 4.4 – Image of copy of the file to be uploaded to /var/ftp/pub .

The scripts made were called download_Urbisnet_script, upload_Urbisnet_script.

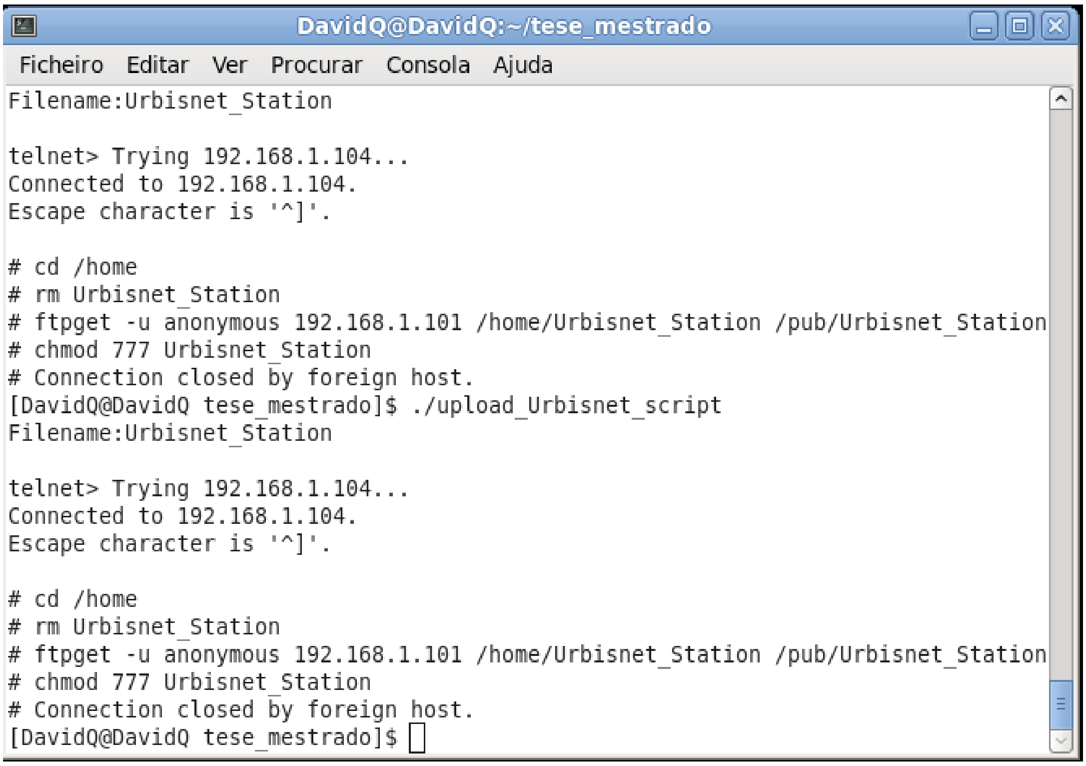

Fig. 4.5 – Image of the upload of a file to the Urbisnet Station.

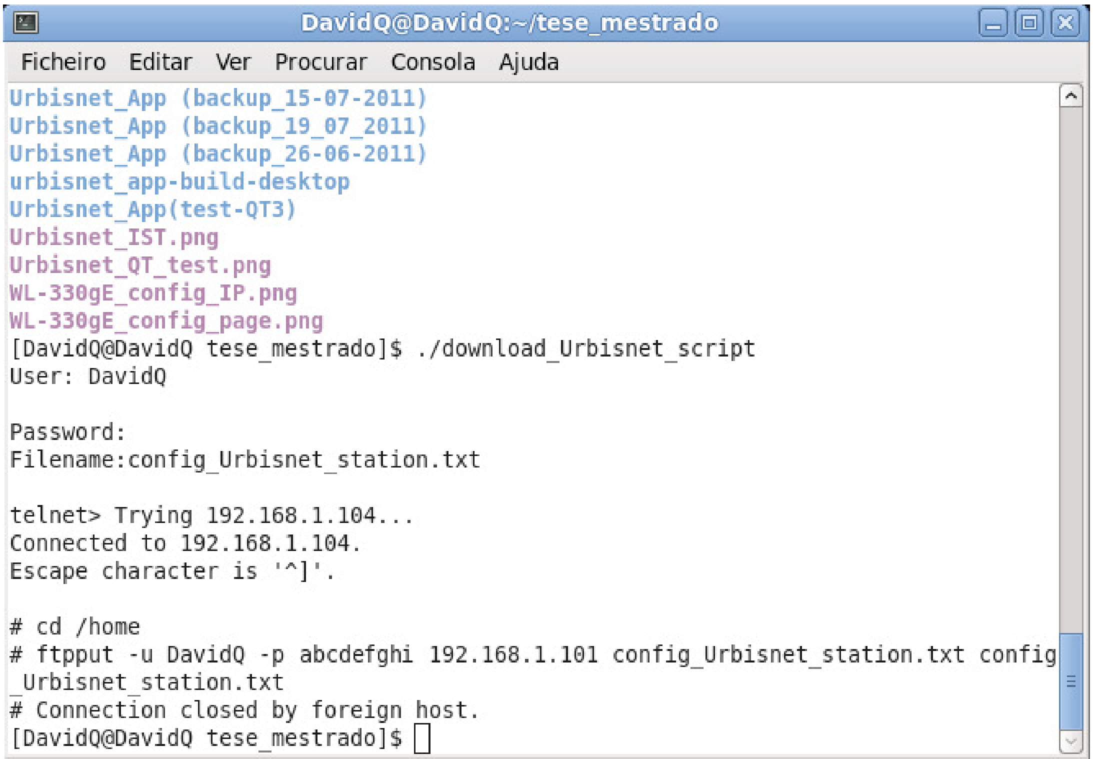

Fig. 4.6 – Image of a download of a file to the Urbisnet Station.

5 – Test of the Mobile Air Quality Station

5.1 – Gas sensor calibration tests

The gas sensors were calibrated, for that purpose it were made calibration tests at ISQ (Instituto de Soldadura e Qualidade). The calibration tests had the objective to calibrate all the gas sensors, for the gas concentration range usual on the measurement of outside air quality. The standard apparatus used at ISQ to stimulate the gas station, with known concentrations of gases, is based on gas bottles that have a know concentration of the pollutant gas. The bottles are then connected to a gas dilution system, which is a device that mixes the Nitrogen/pollutant_gas mixture with pure Nitrogen, through a mechanical system of valves, to produce a different but precise known concentration of the pollutant. The Nitrogen gas is used in the dilution process because is the main constituent of the Earth Atmosphere, and because it is considered an inert gas (doesn't participate in chemical reactions). The station should be place inside a sealed compartment, with an input valve and an output valve, so that the compartment atmosphere can be renovated by the gas dilution system, allowing to obtain a controlled and known atmosphere.

It were made 3 test attempts at ISQ to calibrate the gas sensors, at the last test Prof. Francisco Alegria was present to help overcome the difficulties experienced. The sensors used with the station were selected and made available to me by the thesis coordination, the only sensor that was selected by me was the Alphasense CO2 IRC-A1 NDIR.

At the sensor calibration tests, it was quickly discovered that the SO2-BF was sensible to SO_2 concentrations much higher that the concentration range used on the measurement of air quality. So this sensor couldn't be used to accomplish the project objectives.

The sensors for O_3, CO, NO_2, are based on metal oxide crystal that absorbs negatively charged oxygen molecules, in the initial tests made at ISQ the atmosphere of the test container had present only Nitrogen and the pollutant gas that was intended to be measured. So in the atmosphere used on the sensor calibration tests there wasn't available the oxygen gas, that is the main element to make the sensors work. So all the data that was registered for these 3 sensors, wasn't registering their variation with the presence of the pollutant gas, but their variation with the lack of oxygen. So it isn't useful. It was made a test to confirm this, the sensors were stimulated with an atmosphere that had only pure nitrogen and was observed a large variation in the sensor output.

These type of sensors are very sensitive to several environmental conditions like temperature, humidity, atmospheric pressure. Also these sensors never are sensitive to only one air pollutant, they are designed to be more sensitive to one pollutant, but are always sensitive to several air pollutants which makes the measurement of the small concentrations usual to the measurement of the air quality very difficult. So these sensors are not appropriate to the measurement of outside air quality.

A different calibration procedure was tried at ISQ, with the sensors placed in room atmosphere but covered with a small cap connected to the gas dilution tube, the gas dilution system was connected to a bottle of synthetic atmosphere to dilute the gas in normal atmosphere (with 21% oxygen), allowing the sensors to function properly. But even under these conditions the sensors based on heated oxide semiconductor showed an unstable output, with some occasional variations that didn't matched the stimulus that was applied.

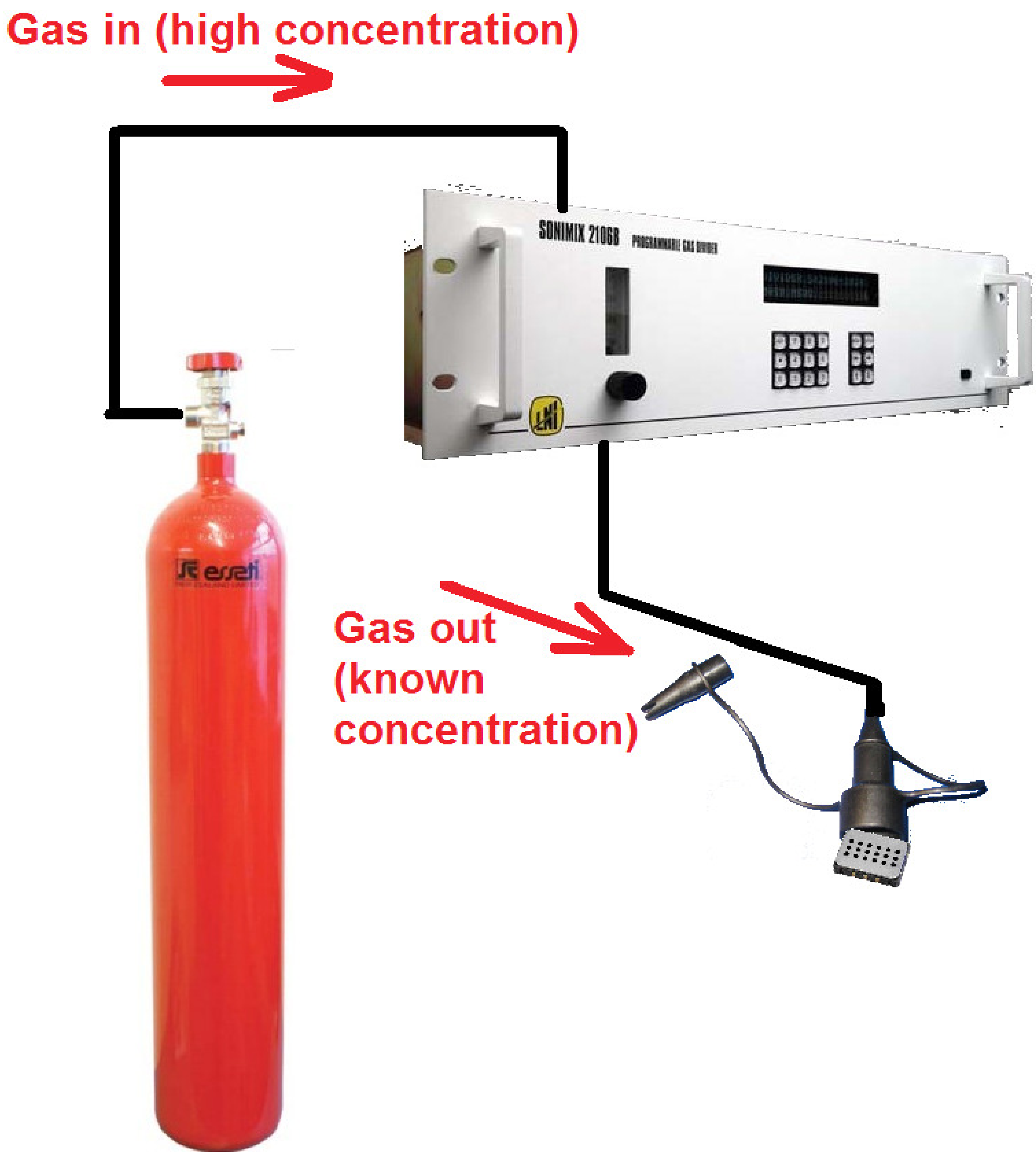

Fig. 5.1 – Diagram of the apparatus used to calibrate the MICS-4514 CO and NO_2 gas sensor.

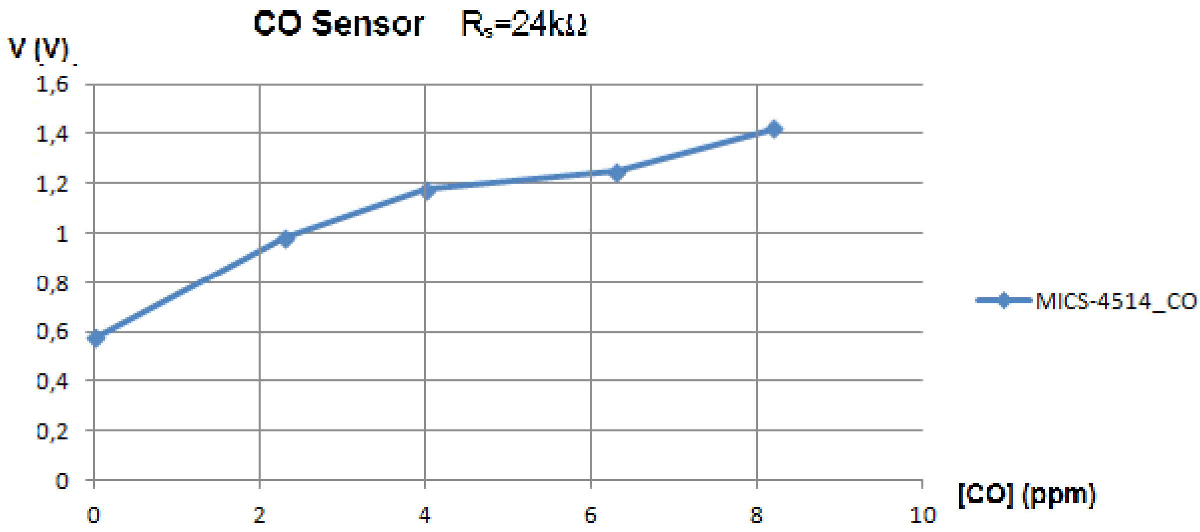

Fig. 5.2 – Graph of the data obtained in the calibration MICS-4514 CO sensor, when stimulated with different concentrations of CO in a normal atmosphere.

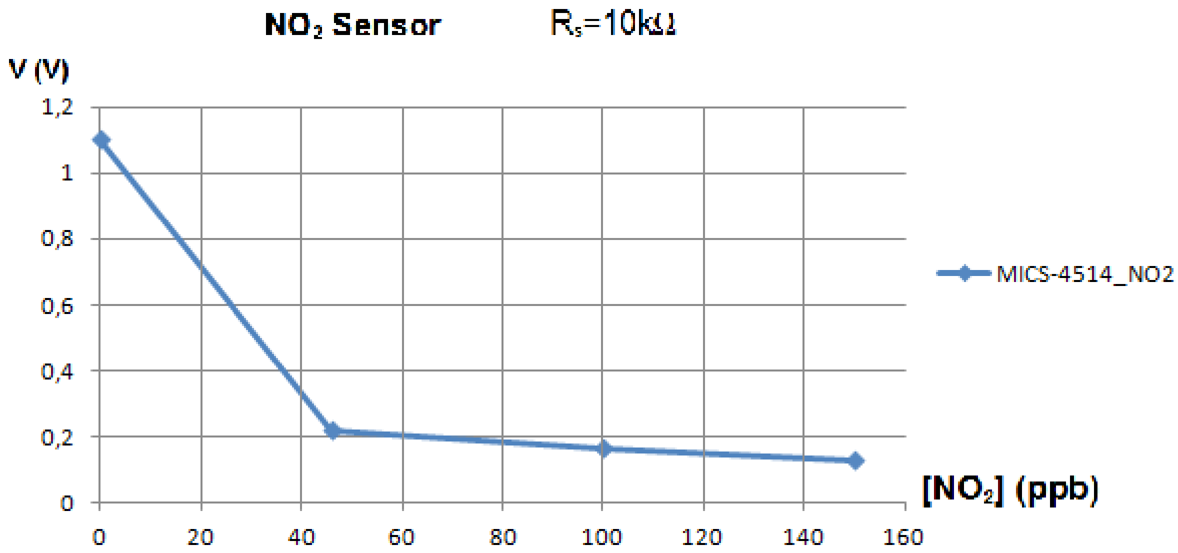

Fig. 5.3 – Graph of the data obtained in the calibration MICS-4514 NO_2 sensor, when stimulated with different concentrations of NO_2 in a normal atmosphere.

The sensor for CO_2 used is based on the absorption of infrared light by the CO_2 gas. This sensor has an active and a reference channel, so it has some immunity to all the environmental conditions that can affect the sensor output. This behavior was clearly observed at the tests made at ISQ, the sensor output was substantially increased on the active and reference channel by the nitrogen atmosphere, but was only observed a difference between the active and reference channel when it was present the CO_2 gas.

The calibration for the CO_2 sensor was made not in the sealed compartment, but was instead used a small cup to cover the sensor with the gas tube connected to the top of the cup, like this the output isn't so strongly affected by the pure nitrogen or the atmospheric pressure present inside the sealed compartment.

Tab. 5.1 – Table with the calibration data for the IRC-A1 CO_2 sensor.

[CO_2] (ppm)	**Activo_NDIR (V)**	**Referência_NDIR (V)**
0	0,749512	0,741577
2502	0,69038	0,739136
4991	0,6073	0,69519
7505	0,59204	0,698242
10000	0,554199	0,690918

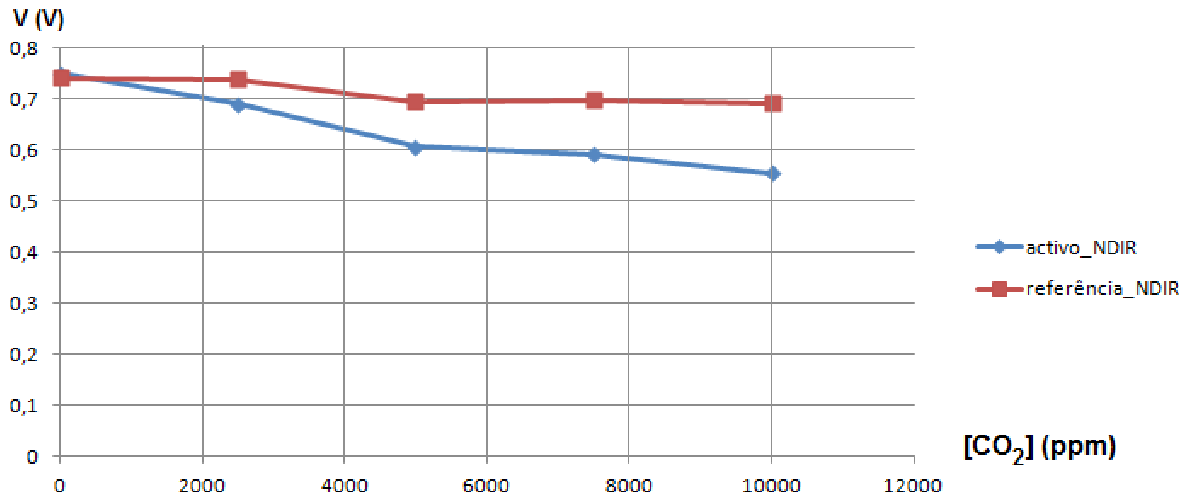

Fig. 5.4 – Graph of the CO_2 sensor output related to the gas concentration.

ZERO=ACT_0/REF_0, SPAN=$ABS_x/(1-\exp(-bx^c))$, ABS=$1-(I/I_0)$, I=ACT/REF, ABS=1–(ACT/(REF×ZERO))

$$x=\left[\frac{\ln(1-(ABS/SPAN))}{-b}\right]^{(1/c)} \qquad (5.1)$$

ZERO=0.749512/0.741577=1.011 , $ABS_{4991ppm}$=1–(0.6073 /(0.69519×1.011)=0.1357, SPAN=0.1357/(1–exp(–4.3x10^{-4}×$4991^{0.89}$)), SPAN=0.2386

$$x[ppm]=\left[\frac{\ln(1-(ABS_x/0.2386))}{-0.00043}\right]^{1.124} \qquad (5.2)$$

For example, if you want to know the concentration when ACT=0.5542 and REF=0.69092.Then you calculate ABS_x = 1–(0.5542/(0.69092×1.011) = 0.2066, x=13321 ppm (experimentally this is correspondent to 10000 ppm).

This was the measurement procedure as recommended on one of the application notes of the manufacturer, but as it was shown there is some error between the expected (10000 ppm) and what it was obtained by the calculations (13321 ppm). I don't know if this error comes from lack of precision on the calibration points obtained experimentally or if it is the method suggested by the manufacturer that isn't good has expected. A simple way for the user to overcome this can be: make a calibration process with good precision, and at the calibration get a large number of points from different concentrations to obtain enough data to draw a point graph, where the samples taken are connected with lines. Then the user can convert the voltage read on the sensor to the concentration from the graph.

5.2 – Power consumption and temperature tests

The power consumption of the station was measured, when is in stand-by and when making measurements and transmitting data. It was found that the power consumption is almost constant and independently of being in stand-by or making measurements and transmitting data. The measured power consumption was 7.5 W when using an input voltage of 11 V.

During the tests made the Urbisnet station (with a black enclosure) was tested on the outside, under the intense summer sun, and it has registered temperatures of 53 ºC inside the box, the functionality of the station wasn't affected by the elevated temperature. It is expected that under the same conditions the station should reach much lower temperatures if a shining metal enclosure is used. A shining metal enclosure is preferred because it would absorb much less sun light leading to a lower temperature inside the station.

5.3 – Test of the station waterproofing

As is was explained before, the station enclosure has a system of two lids per face to allow the air flow but still block the rain from reaching the inside of the box.

A test was made with the box closed with the dual lids and the Teflon tape on a bath shower, with a water jet hitting the box from the top and with maximum angle from the vertical of 30º for duration of 3 minutes. A large piece of toilet paper was previously placed inside the box, after the test was finished the paper was dry. The fact that the electronic boards of the station are suspended on the longitudinal supports, makes more difficult for the board to catch any water droplets from the rain.

Although there isn't a guaranty that no water will enter the box, under normal conditions it is expected that only some droplet could pass in, and would probably stay on the bottom of the box, away from the electronics. For assuring a better protection the electronic boards, they can be wraped around flexible plastic sheet.

6 – Conclusions

The work done for the master thesis evolved some research about air pollution issues, methods used to measure air pollution and information about the equipments related to the measurement of air pollution. The information collected is interesting and useful for the execution of the work of the thesis and possibly interesting to someone working in a related area that would read the report.

The gas sensors were selected for the station, the correspondent circuit for the sensors was designed and tested on a breadbaord, the sensors and circuits were mounted on a PCB, and the sensors were tested for calibration on ISQ. Through this process was possible to evaluate the sensors and conclude their appropriateness to the work. A report for the sensors was made and alternative sensors were suggested.

The humidity and temperature sensor, the ADC, the Ethernet interface, the serial interface, and the C10/3 were placed together on the Urbisnet BASE board. They form the core hardware of the Urbisnet Station that is versatile to interface with the sensors or possibly with different sensors, as well be programmed to different functionalities at the user will.

All the hardware was fit inside the chosen box, and is able to communicate with other machines through GSM or WIFI. The box was tested and was shown that it could protect the inside hardware form the rain on the specified conditions.

The ASUS WL-330GE router was modified to be connected to the external WIFI antenna, and was configured as access point placing its Ethernet connector and WIFI network on the same LAN.

There were found several difficulties in the development of the Urbisnet hardware, these difficulties were overcome resulting in the development of a fully functional hardware and the creation of knowledge for the people evolved in the project, and the personal development of several analytical and practical skills on electronics. I developed competences in the project of I2C, RS232, Ethernet hardware, on producing applications with graphical interface for Linux, on the programming of applications with communication through the Internet, on the configuration of routers and the production of scripts to automatically configure the hardware and launch drivers and applications when the Linux boots up.

At the current state the station can send and receive sensor data through the GSM and WIFI communications, can read with very good accuracy the temperature, humidity, geographical coordinates. It can measure the CO_2 gas concentration with good accuracy.

The part that is not fully functional is the measurement of the gas concentrations for CO, NO_2, O_3, SO_2, because of the problems encountered on gas sensor calibration and on the sensors itself. This is not very problematic, because in future work for the Urbisnet project, there can be done several changes to solve this issues. The board with sensors can be easily replaced with another board because it's connected to the main board with a flat cable. So different gas sensors can be used with the current hardware, possibly more adequate sensors to measure low gas concentrations and with good selectivity to specify which gases are present in the atmosphere. Of course such sensors would be much more expensive, and probability will occupy more volume, but I don't think that would make the station economically unviable. I think the project objectives were achieved by me the best I could achieve with the resources that were made available to me by the professors coordinating the project.

An estimation of the low volume production of the station was made on Appendix 5 and the cost was estimated to be around 512 €.

The user of the station can easily change the sensor's board of the Urbisnet Station, this can be achieved by disconnecting the flat cable from the sensor board and connecting to another sensor board designed to work with the Urbisnet Station. This way different sensors can be used to measure air pollution, possibly the user is available to spend some extra money on sensors and so buy sensors more selective and more appropriate to measure low concentrations.

The best sensors found that would have a size and mode of operation adequate with the Urbisnet station are:

SO_2: Alphasense has recently developed a sensor for measuring low concentrations of SO_2, that is very selective and also has a size that is within the dimensions required for the work, , the only negative aspect of the sensor is that it requires a large signal conditioning circuit. The sensor is the SO2-B4, it's an electrochemical cell with 4 electrodes, that has a resolution for measuring SO_2 of 0.005 ppm [37].

Fig. 6.1 – SO2-B4 Sulfur Dioxide, Alphasense.

CO: E2V manufactures a CO gas sensor suitable to measure low concentrations of CO that also has a high selectivity, it is the EC4-500-CO. This sensor is an electrochemical cell, with a resolution for CO of 1 ppm. It also has a size that is compatible with the station [34].

Fig. 6.2 – EC4-500-CO, CO gas sensor, E2V.

O_3: For the measurement of O_3 there is a new design of gas sensor that is under development and isn't yet as far as I know on sale, it is based on the resistance variation, the sensor is made from indium oxide nanoparticles, with an integrated near ultraviolet LED that stimulates the sensor. This kind of sensor doesn't requires to be heated, and so the problems related to temperature change don't exist. In accordance with the researchers the sensor can read concentrations as low as 30 ppb.

These sensors as I know are developed by the Fraunhofer Institute for Applied Solid State Physics, Freiburg, Germany [35].

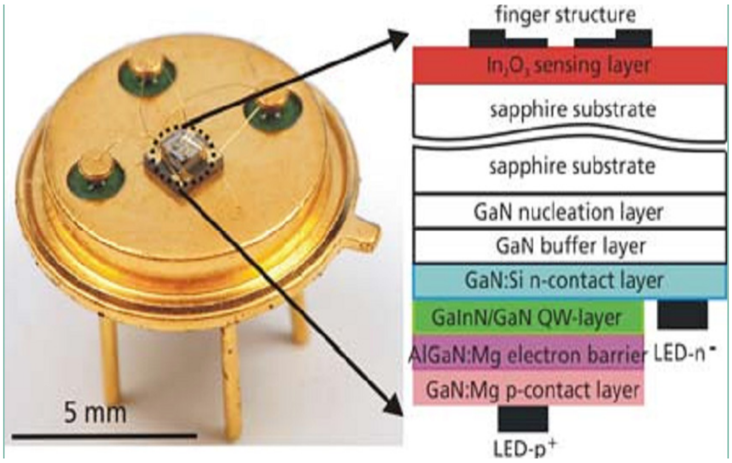

Fig. 6.3 – New gas sensor, O_3 gas sensor.

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Appendix 1 – Rudimentary sensor test equipment

A rudimentary test equipment, was built to check the sensors functionality and to have a better opportunity to learn how the sensors work. This set of equipment where in part given to me by my Thesis Coordinator and in part bought by me, part built on the workshop of IST-Taguspark.

Thanks to Mr. Pina dos Santos for all the advice and support. The equipment is made of an aquarium-like box with fan and an aquarium air pump that is mine and that it was purposely modified to suck air instead of the original functionality to push air, and also an aluminum cake pan where the lid was replaced for a custom made lid (made from scrap sheet metal). The aluminum cake pan is used as a combustion chamber to produce the typical combustion gases (the fuel used was only old newspaper), then the gases are sucked by the aquarium air pump into the GAS Test-Box (aquarium-like box), inside the tube connecting to the GAS Test-Box there is a cigarette filter to clean all the smoke particles, reducing the probability of contaminating the sensor permanently, because of the intense smoke exposure if the filters weren't used. The 3 described components are connected trough aquarium air tubing, and the connectors to the boxes are made of perforated cork. The aquarium air pump needs some maintenance because the smoke passing through the pump makes the air valves get sticky and making the pump malfunction. To solve this problem the air pump must be fully disassembled and the air valves should be cleaned to work normally again. It is recommended that the cigarette filter is placed inside the tube connecting the combustion chamber to the air pump to reduce the pump exposure to the smoke, but the filter should be placed in the tube at a safe distance from the flames of the combustion chamber, so don't put the filter in the tube tip that stays inside the combustion chamber (that is the easiest place to put the cigarette filter because of greater that the tube diameter of the filter).

a) **b)**

Fig. A1.1 – a) View of the open combustion chamber, b) view of the closed combustion chamber.

a) b)

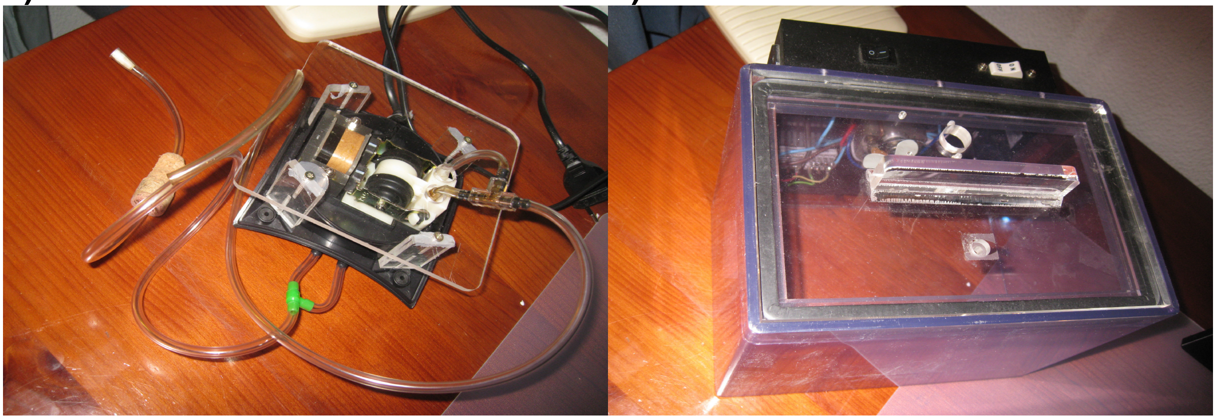

Fig. A1.2 – a) Modified aquarium air pump (sucks air), b) GAS Test-Box, (aquarium-like box).

Fig. A1.3 – Complete set to make rudimentary tests for the sensors.

To test the ozone gas sensor a different apparatus was used. It was used a modified home ozone generator air cleaner (cleaner or not!!), to produce the ozone gas, and a plastic water bottle as the GAS-Test-Box.

Fig. A1.4 – Complete set to make rudimentary tests on ozone sensors.

Appendix 2 – Development Environment

The Development Environment provided by the board manufacturer is the Eclipse (Linux version) configured to compile code with a specific C compiler for the ARM processor. The manufacturer supplies the Development Environment in a setup installer, which installs in Windows Operating System the CoLinux Linux distribution, which should work alongside Windows, it also installs a image of the Colinux File system (that comes in the file root_fs.img inside the installer program). The CoLinux development environment as stated by the Telit (The manufacturer of GE863-PRO) is only compatible with Windows XP Professional. It was made an attempt to install the Development Environment on Windows 7 Professional 64-bit, but the CoLinux made Windows crash at Start-up for reasons that are unknown to me, making Windows totally not operational, so it was necessary to uninstall the Development Environment. Also an attempt to install the Development Environment on Windows XP Professional was made, the CoLinux run on windows apparently well, but to be able to access the Linux Console or a GUI (Graphical User Interface) the user should use Xming (Program to Remote GUI for Linux), and through the TCP/IP protocol making a connection to the localhost access the CoLinux. Attempts to open the GUI or the Linux console were made but without success, and I personally thought that the Development Environment was too complicated just to run Eclipse Platform.

So I decided to Install Eclipse in a way that I consider simpler. The Setup Installer was extracted with a freeware extraction program (I used “Universal Extractor”). In the Directories of the extracted Setup Installer there is the file “dskimageC_Cpp_18_7_2008.exe”, that is a Self-extracting archive, after extracting that file, one of the extracted files is root_fs.img. It was used Fedora 14 Linux distribution, on Fedora 14 the file root_fs.img was mounted, and the CoLinux File system was accessed, there it was copied to Fedora 14 File System the directories “/opt/crosstools” and “/opt/eclipse”. After that, the Eclipse Platform can be executed from the Fedora 14, and this version of Eclipse is already configured to compile the C code in the ARM C compiler that is inside the directory “crosstools”.

To start the Eclipse platform the User should open the Linux Console and insert the following commands: “cd /opt/eclipse↵ ” and “./eclipse↵” (↵ indicates pressing the ENTER key) [31],[32].

Sometimes when the Eclipse Platform is starting-up the following error is displayed:

> A fatal error has been detected by the Java Runtime Environment:

>

>

> SIGSEGV (0xb) at pc=0x04202c1d, pid=5214, tid=3079239712

>

>

> JRE version: 6.0_20-b20

```
> Java VM: OpenJDK Client VM (19.0-b09 mixed mode linux-x86 )
> Derivative: IcedTea6 1.9.3
> Distribution: Fedora release 14 (Laughlin), package fedora-49.1.9.3.fc14-i386
>
> Problematic frame:
> C [libxul.so+0x9c7c1d]
>
> An error report file with more information is saved as:
> /tmp/hs_err_pid5214.log
>
> If you would like to submit a bug report, please include
> instructions how to reproduce the bug and visit:
> http://icedtea.classpath.org/bugzilla
>
> Aborted (core dumped)
```

To solve the described problem the User should disable browser functionality in Eclipse (this is to disable the plug-in of an Internet browser in Eclipse platform), the plug-in of a Internet browser isn't necessary to write, compile or debug C code. In order to disable plug-in support the user should edit the file “/opt/eclipse/eclipse.ini” and add to the end of the file the following line:

“-Dorg.eclipse.swt.browser.XULRunnerPath=/dev/null” , (the “” are not included in the line to be written to the file).

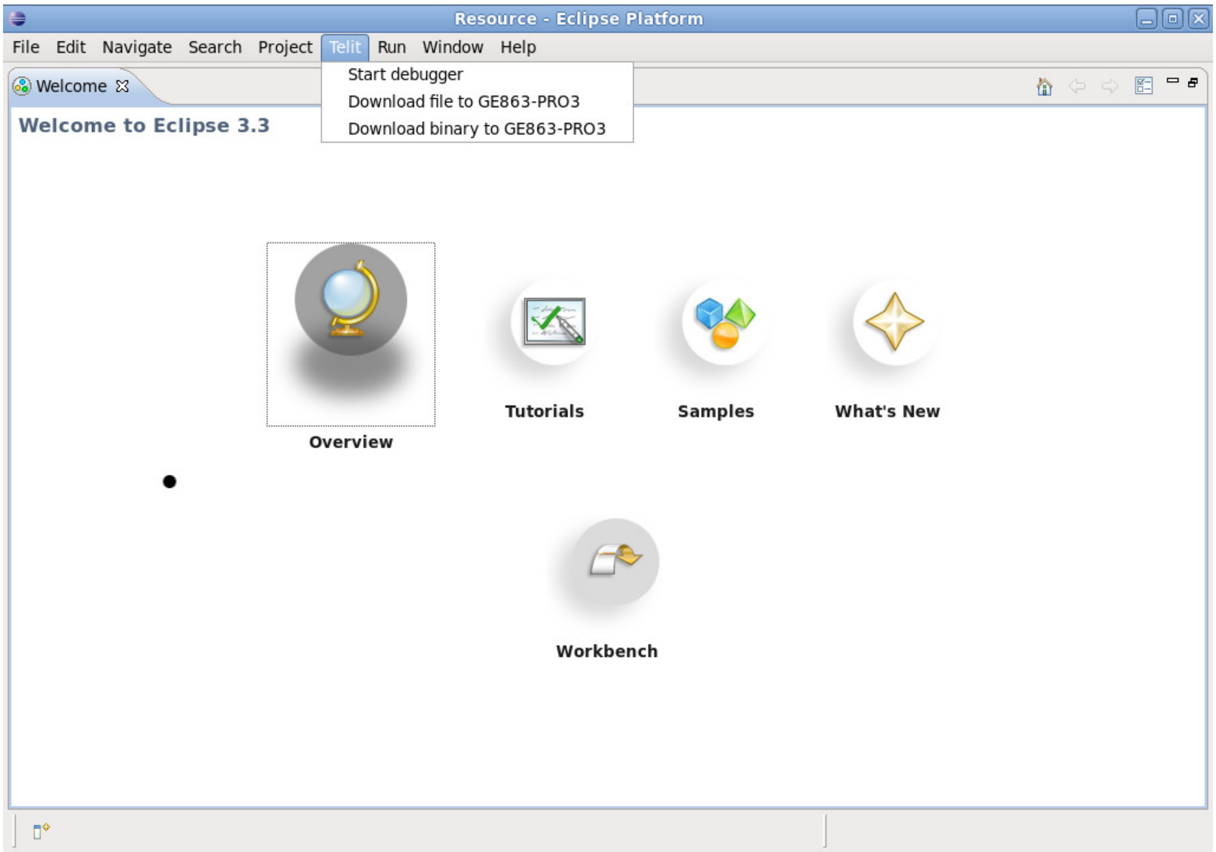

Fig. A2.1 – Screen-shoot of the Eclipse Platform window, it is visible the Telit menu that is a specific menu of the customized Eclipse that was installed, from this window is possible to start the debug on the target system, or to download a file to the File system of GE863-PRO3, or download to the target the last compiled program.

In order to create a new project for compiling C code for the Linux ARM target on Eclipse Platform the User should follow the steps:

1. File->New->C Project, this should open a window called "C Project".
2. On the window "C Project" the User should indicate the project name and the directory of the project (the directory of the project usually is always inside the path "/home/"User"/workspace"), and for the project type chose "ARM uclibc C executable".
3. On the last window called "Project Configuration" the User should select "Release", and click "Finish" button to create the C project for ARM Linux.

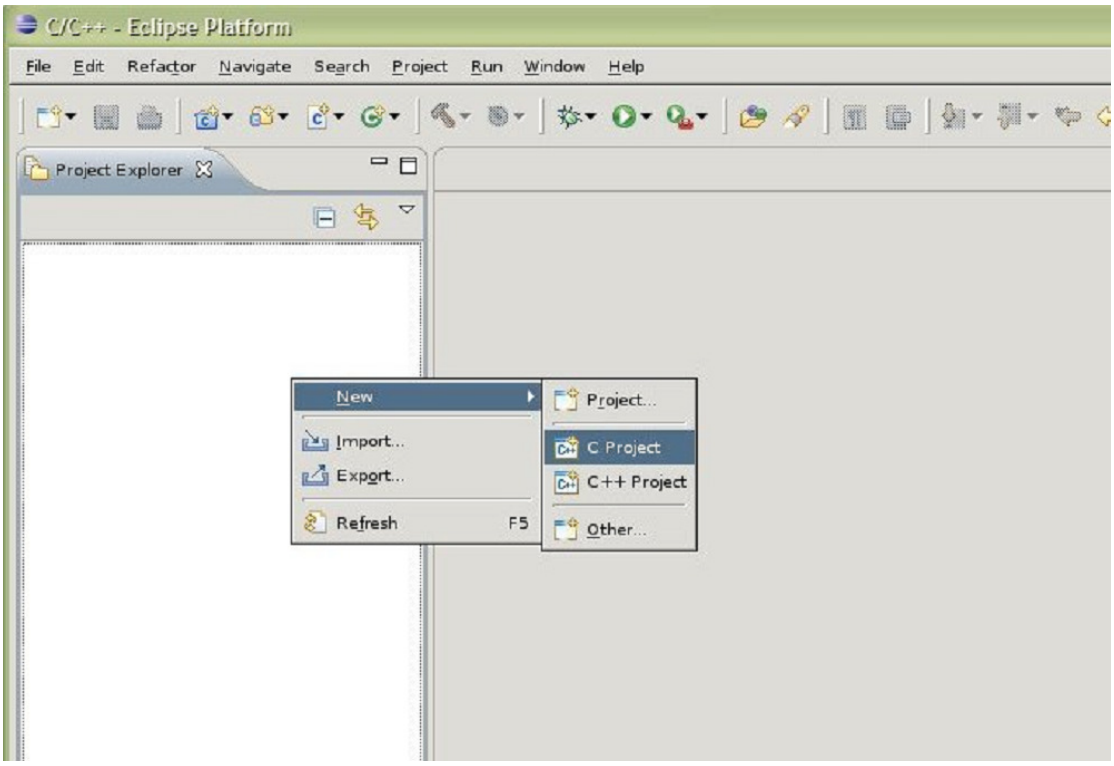

Fig. A2.2 – How to create a new project for Eclipse Platform.

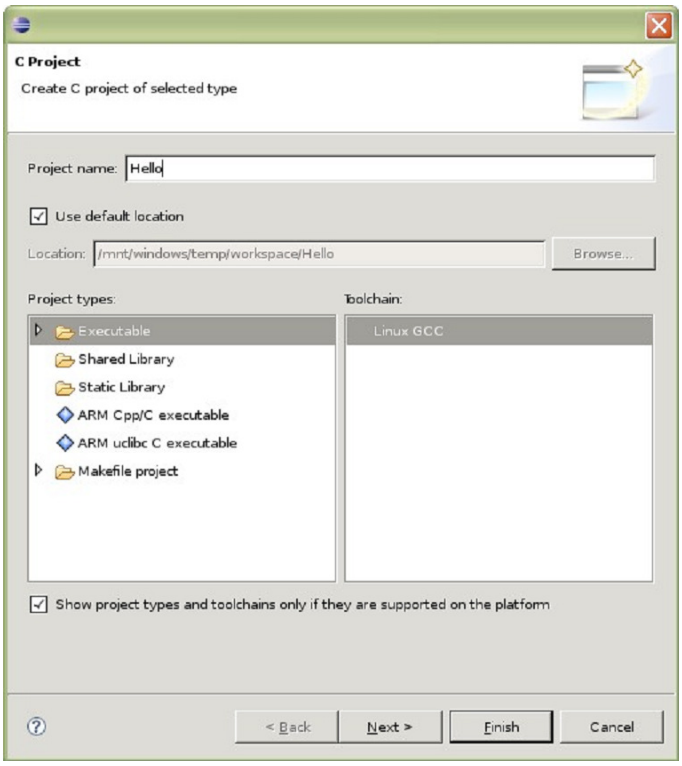

Fig. A2.3 – Settings for a new C project to be compiled for the ARM Linux target.

In order to be able to download files and preform debug on the C10/3 board on the Eclipse Platform the User should be aware of the following issues:

1. The board C10/3 in order to be able to connect to an Ethernet network must have an adapter board that implements the Ethernet protocol and connects to the ARM Microprocessor Fast Ethernet MAC-block through the Media Independent Interface (MII), this board is called "Easy Debugging Ethernet adapter for Aarlogic C10/3".
   This Ethernet interface is already built in the base board, so in the Urbisnet station the user should connect the PC to the Urbisnet WIFI network.

Fig. A2.4 – Easy Debugging Ethernet adapter for Aarlogic C10/3.

2. The user should install an FTP server on the PC Linux in order to use the ftpget and ftpput commands to send and receive data to the Urbisnet Station.

3. The ftp server must be activated, this can be done through Services functionality of the Linux Operating System. The service name is vsftpd.

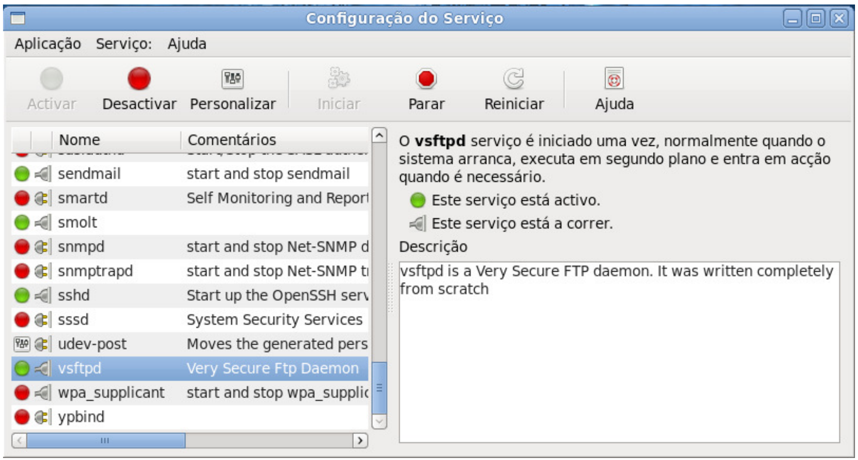

Fig. A2.5 – Services functionality window of the Linux Operating System.

4. The Firewall of the Linux Operating system should be configured to allow communications of port 21 (FTP). This can be done through Firewall Configuration functionality of the Linux Operating System.

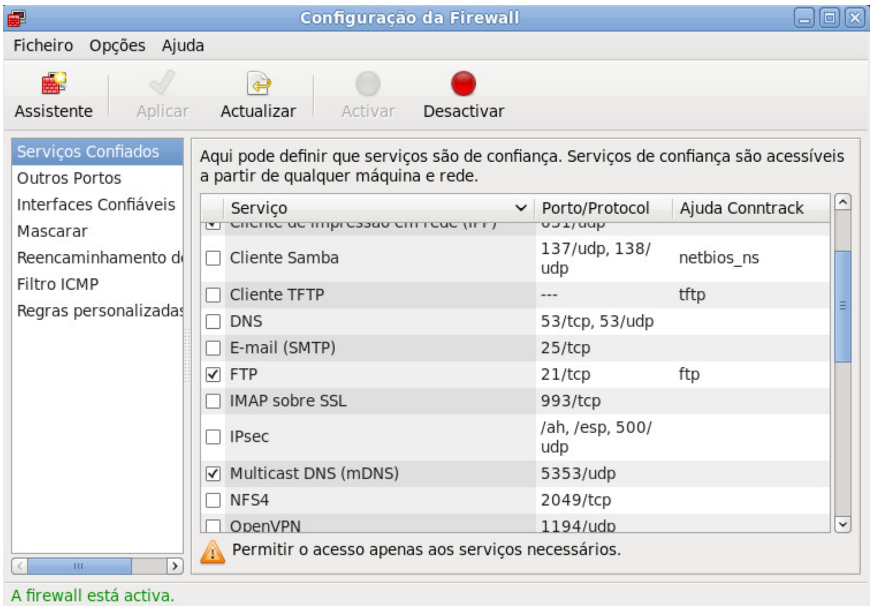

Fig. A2.6 – Firewall Configuration functionality window of the Linux Operating System.

Appendix 3 – Start-up scripts (placed on the folder /etc/init.d)

/etc/init.d/S02

```
#!/bin/sh

cd /lib/modules/2.6.24-rc5-rt1/kernel/drivers/char/
/sbin/modprobe at91sam9260_gpio
```

/etc/init.d/S03

```
#! /bin/sh

modprobe macb

ifconfig eth0 hw ether 06:00:AA:BB:CC:02
ifconfig eth0 192.168.1.104
telnetd

modprobe i2c-core
modprobe i2c-algo-bit
modprobe i2c-dev
modprobe i2c-gpio

ifconfig eth0 up

mount -t vfat /dev/mmcblk0p1 /mnt/sdcard
sleep 3
```

/etc/init.d/S04

```
#! /bin/sh

#hostn com o endereço a testar
hostn=192.168.1.220

i=0
for i in 0 1 2 3
do
	ping -c 3 $hostn
	if [[ $? != 0 ]]; then
		echo "Connection unavailable to $hostn"
		echo "reseting wifi bridge..."
		GPIO_GE863-PRO 93 1
		sleep 3
		GPIO_GE863-PRO 93 0
		sleep 15
	else
		echo "Connection available to $hostn"
fi
done
```

In order for the software work properly, the user should install the Linux programs that makes the software run on the Urbisnet Station. The programs to be installed are:

- Urbisnet, Urbisnet_Station , at /home.
- GPIO_GE863-PRO , at /bin
- S03, S04 , at /etc/init.d

Also for the Urbisnet Station be able to communicate through the network interface, the following modification must be done:

On the file /usr/share/udhcpc/default.script , remove the comment symbol "#" from the lines:

```
#       for i in $router ; do
#       route add default gw $i dev $interface
#       done
```

Appendix 4 – Circuit schematics and PCBs

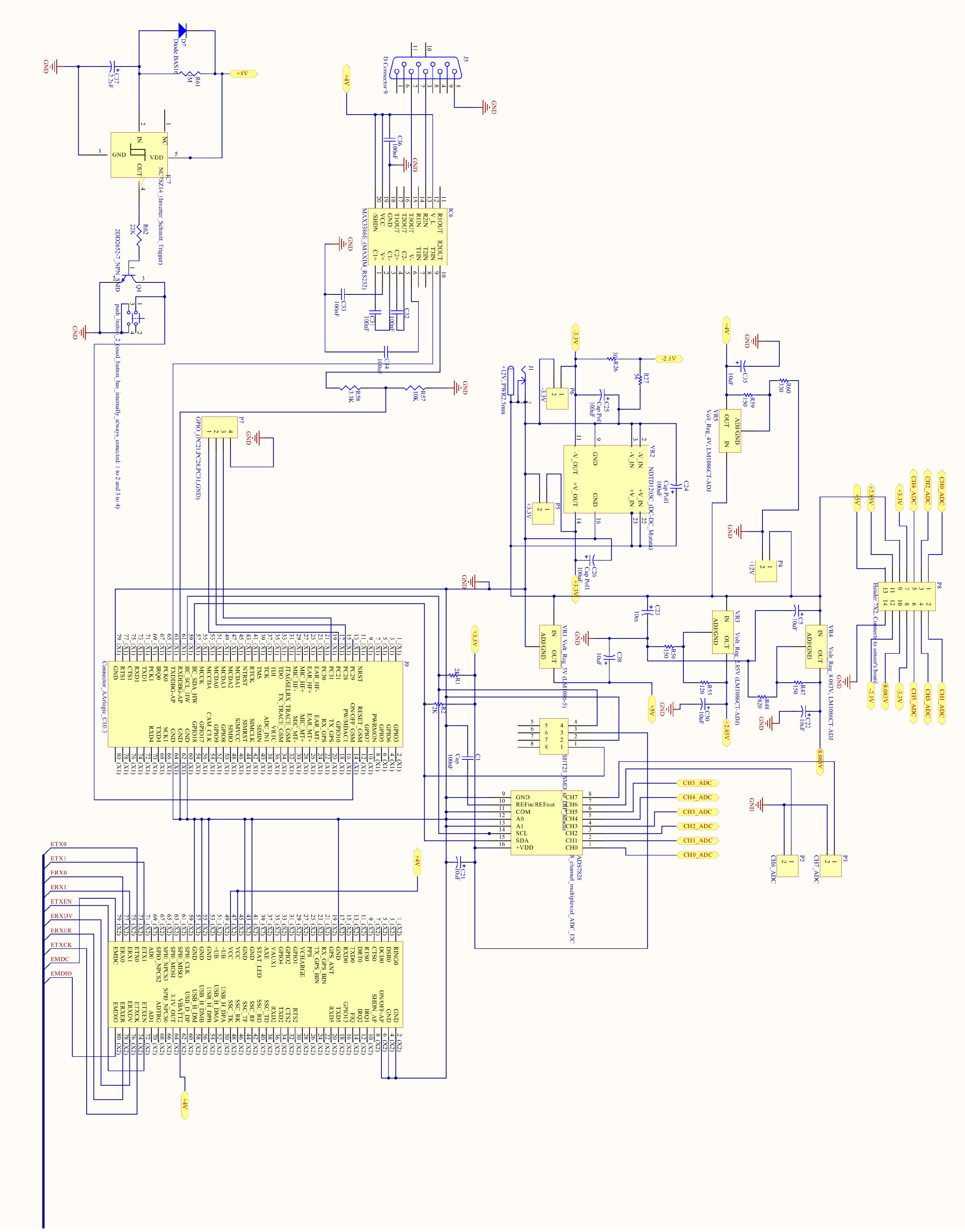

Fig. A4.1 – Schematic of the Urbisnet BASE Board, part 1.

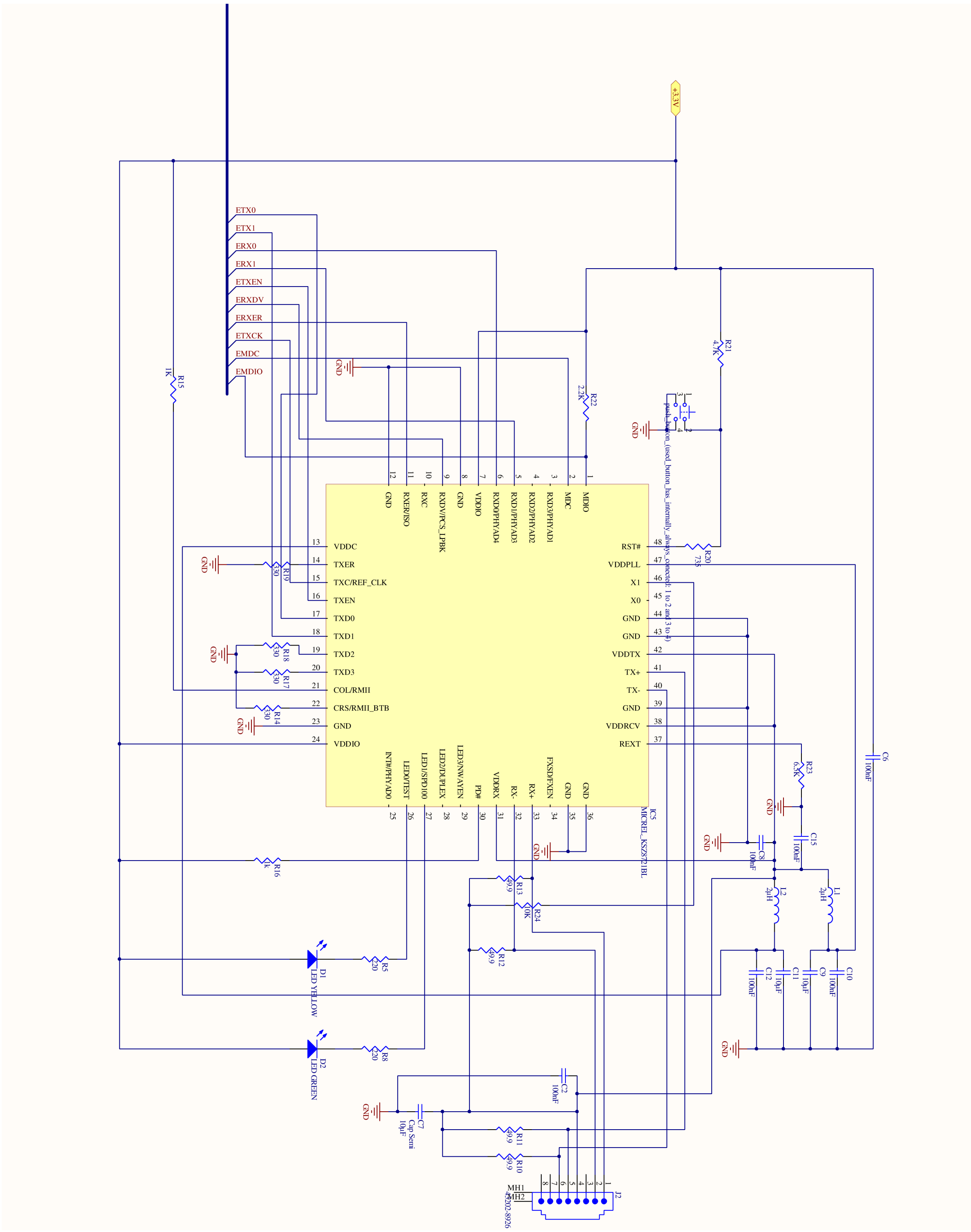

Fig. A4.2 – Schematic of the Urbisnet BASE Board, part 2.

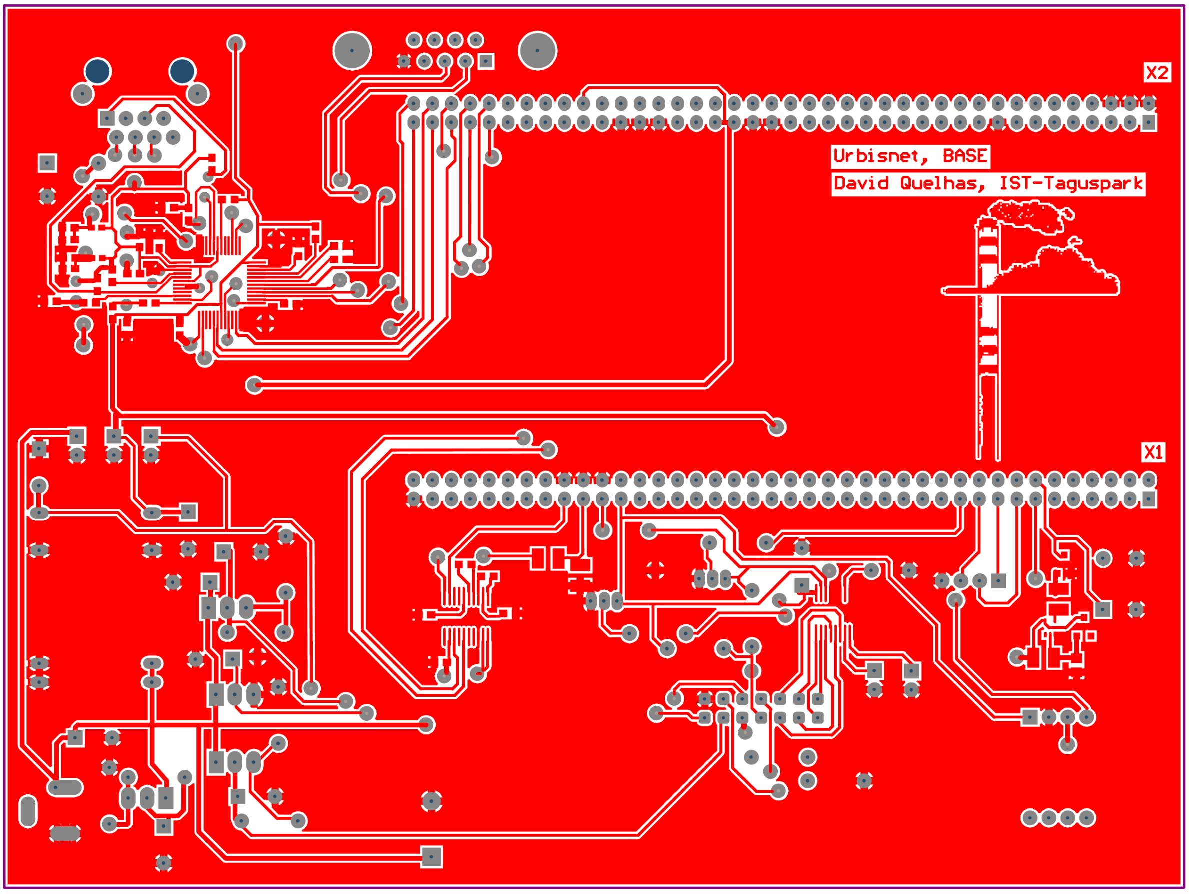

Fig. A4.3 – Urbisnet BASE, PCB top layer.

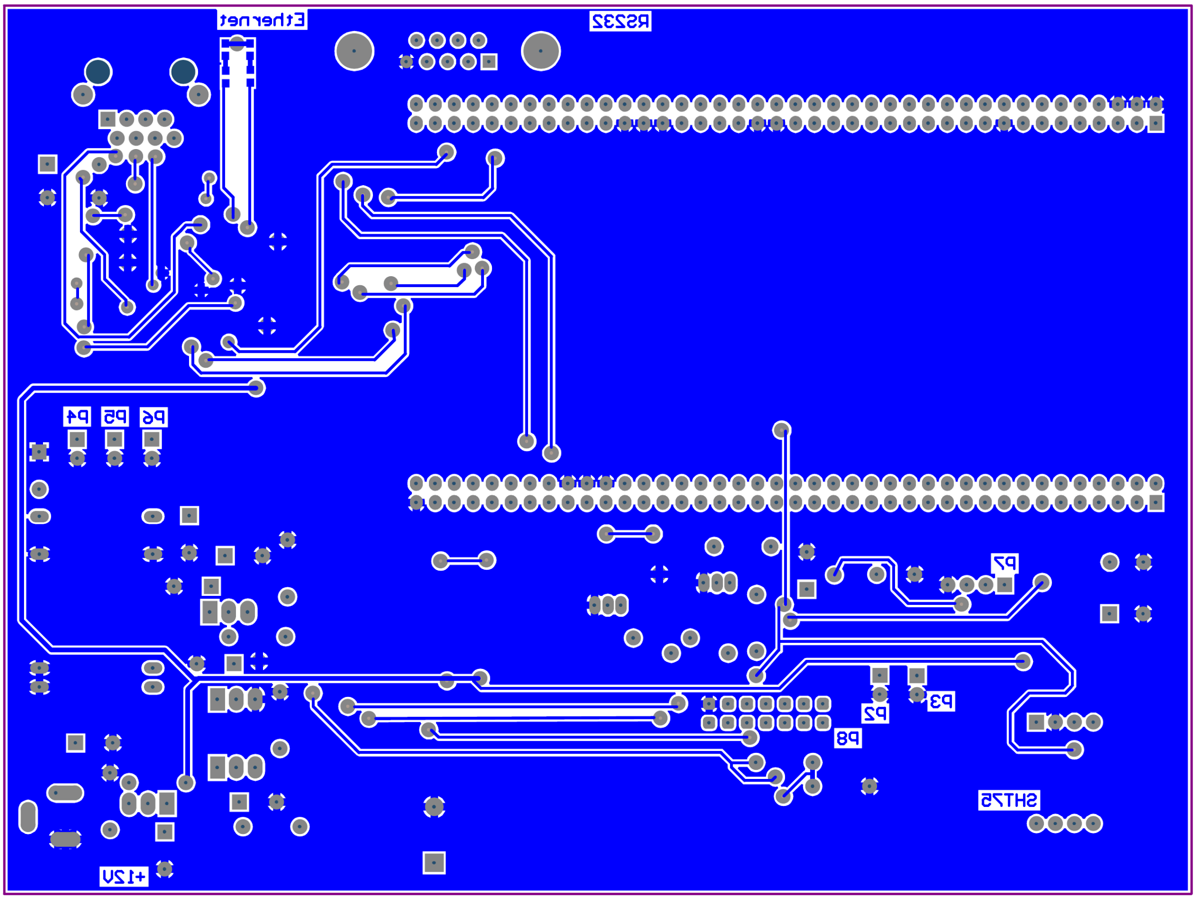

Fig. A4.4 – Urbisnet BASE, PCB bottom layer.

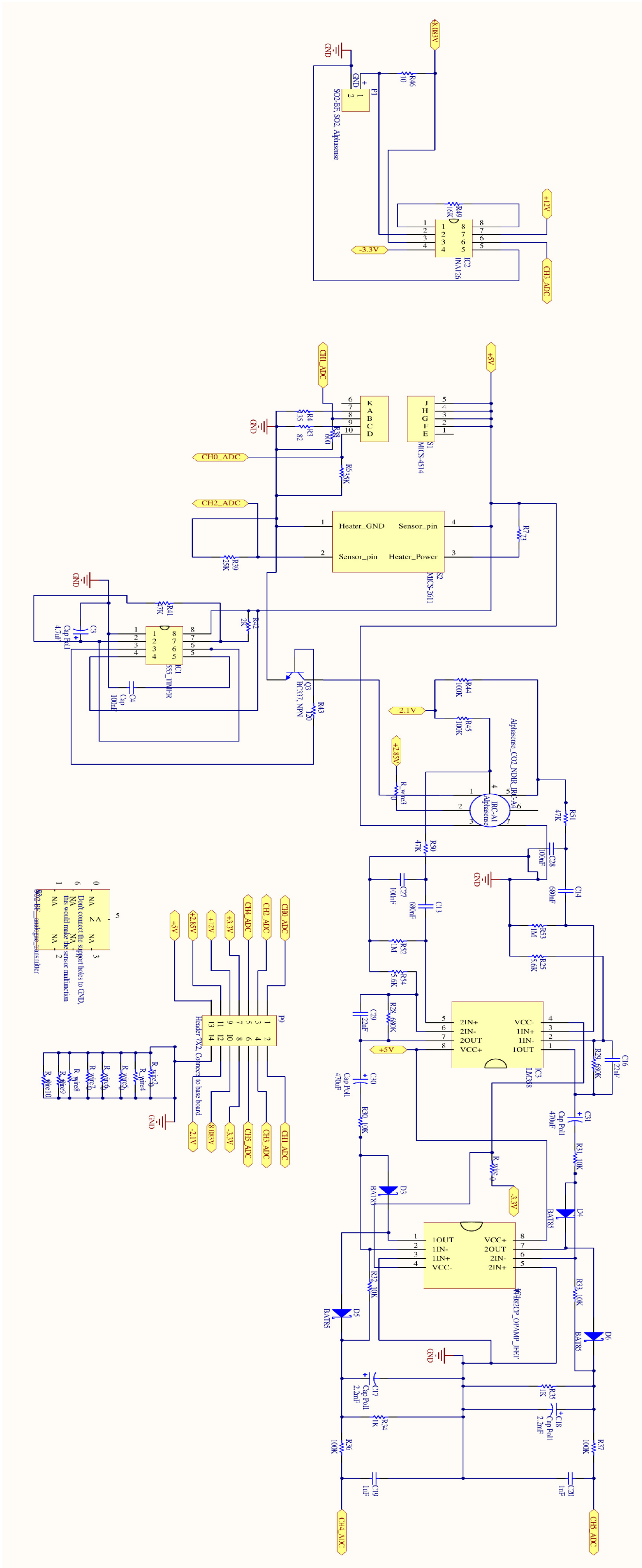

Fig. A4.5 – Schematic of the Urbisnet SENSORS Board.

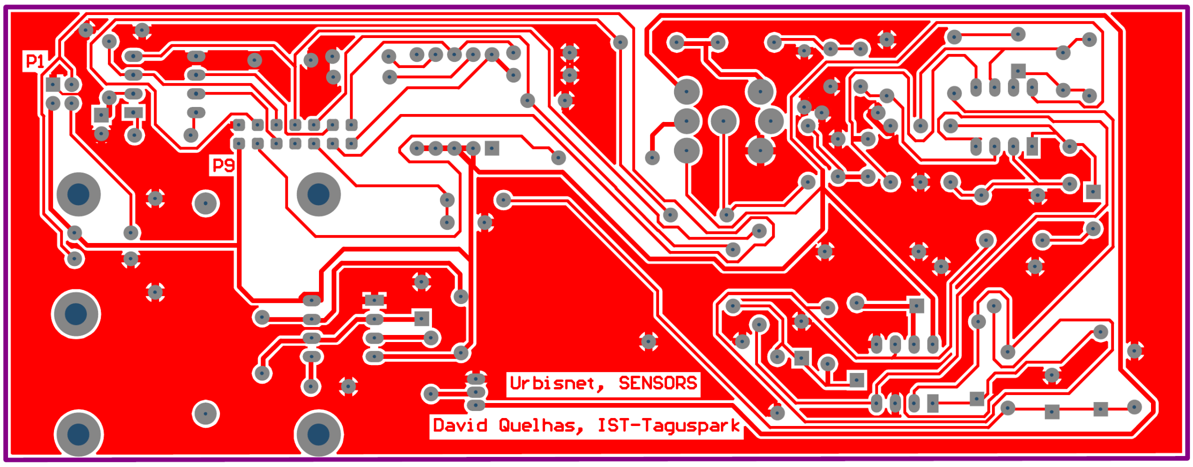

Fig. A4.6 – Urbisnet SENSORS, PCB top layer.

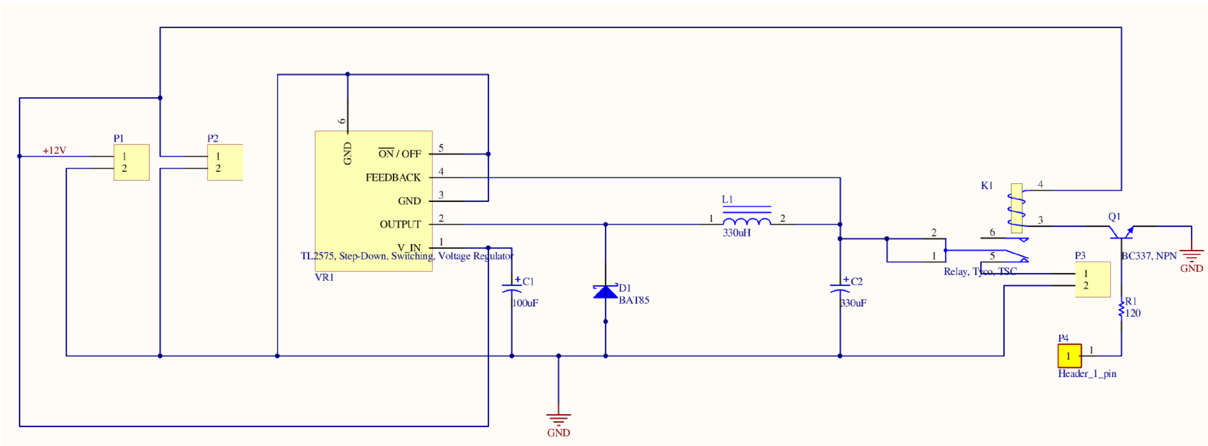

Fig. A4.7 – Schematic of the Urbisnet 12V to 5V converter.

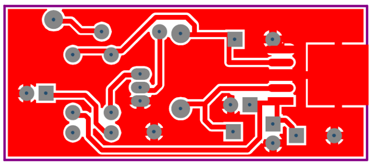

Fig. A4.8 – Urbisnet 12V to 5V converter, PCB top layer.

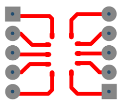

Fig. A4.9 – MICS-4514 SMD to DIP, PCB.

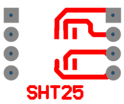

Fig. A4.10 – SHT25 SMD to DIP, PCB.

Appendix 5 – Bill of materials
List of components for the Urbisnet_BASE:

Designator	Value , price	Quantity	Comment
ADS7828	N/A , 7.27€	1	8 channel ADC, I2C, ADS7828
C1,C2,C6,C8,C10,C12, C15,C31,C32,C33,C34,C36	100nF 16V, 12x0.167€	12	Ceramic / polyester film capacitor
C5,C7,C9,C11,C21,C22,C30,C35,C38	10µF 16V, 9x0.065€	9	Electrolytic capacitor
C23	10mF 16V, 2.19€	1	Electrolytic capacitor
C24,C25,C26	100µF 16V,3x0.086€	3	Electrolytic capacitor
C37	2.2µF , 0.03€	1	SMD Electrolytic capacitor
D1	N/A , 0.07€	1	SMD LED Yellow
D2	N/A , 0.07€	1	SMD LED Green
D7	N/A , 0.167€	1	SMD Diode BAS16
IC5	N/A , 5.49€	1	Micrel KSZ8721BL Ethernet transceiver
IC6	N/A , 1.3€	1	MAX3386E,RS232 transceiver
IC7	N/A , 0.31€	1	Inverter schmitt trigger NC7SZ14
J1	N/A , 1.46€	1	Connector,+12V PWR2.5mm
J2	N/A , 4.11€	1	Right Angle, Ethernet plug
J3	N/A , 2.23€	1	Right angle RS232 connector
J9 (various components)	N/A , 8x2.15€	8	This is 8x(2row,20pin header)
push_button, push_button_2	N/A , 2x0.113€	2	Push button with 4 pins, but only 2 electrical nodes
SMD_to_DIP_Header (various components)	N/A , 0.083€	2	This is 2x(1row,4 pin female header)
L1,L2	2uH , 2x0.04€	2	SMD inductor
P2,P3,P4,P5,P6	N/A , 5x0.04€	5	1row, 2pin female header
P7	N/A , 0.083€	1	1row,4pin female header
P8	N/A , 0.072€	1	2row,14pin male header
Q4	N/A , 0.035€	1	BC846, SMD NPN transistor
R1,R2	2KΩ , 2x0.04€	2	1/4W resistor
R5,R8	220Ω , 2x0.028€	2	SMD 1/4W resistor
R10,R11,R12,R13	49.9Ω , 4x0.045€	4	SMD 1/4W resistor
R14,R17,R18,R19	330Ω , 4x0.028€	4	SMD 1/4W resistor
R15,R16	1kΩ , 0.028€	2	SMD 1/4W resistor
R20	735Ω , 0.018€	1	SMD 1/4W resistor
R21	4.7kΩ , 0.028€	1	SMD 1/4W resistor
R22	2.2kΩ , 0.028€	1	SMD 1/4W resistor
R23	6.5kΩ , 0.018€	1	SMD 1/4W resistor
R24	10kΩ , 0.028€	1	SMD 1/4W resistor
R26	30Ω , 0.031€	1	1/4W resistor
R27	56Ω , 0.023€	1	1/4W resistor
R47,R56,R59	150Ω , 3x0.06€	3	1/4W resistor
R48	820Ω , 0.013€	1	1/4W resistor
R55	120Ω , 0.018€	1	1/4W resistor
R57	10kΩ , 0.027€	1	SMD 1/4W resistor
R58	3.3kΩ , 0.013€	1	SMD 1/4W resistor
R60	330Ω , 0.036€	1	1/4W resistor

R61	1MΩ , 0.042€	1	SMD 1/4W resistor
R62	22kΩ , 0.036€	1	SMD 1/4W resistor
VR1	N/A , 2.92€	1	LM1086-5, 5V linear voltage regulator
VR2	N/A , 14.65€	1	NDTD1203C, DC-DC Murata
VR3,VR4,VR5	N/A , 3x1.64€	3	LM1086-ADJ, adjustable voltage regulator
Total:	68.92€		

List of components for the Urbisnet_SENSORS:

Designator	Value	Quantity	Comment
C3	4.7μF 6.3V, 0.05€	1	Electrolytic capacitor
C4,C27,C28	100nF , 3x0.056€	3	Ceramic / polyester film capacitor
C13,C14	680nF , 2x2.29€	2	Ceramic / polyester film capacitor
C16,C29	22nF , 2x0.092€	2	Ceramic / polyester film capacitor
C17,C18	22mF 6.3V, 2x2.21€	2	Electrolytic capacitor
C19,C20	1μF , 2x0.048€	2	Ceramic / polyester film capacitor
C30,C31	470μF 6.3V , 2x0.183€	2	Electrolytic capacitor
D3,D4,D5,D6	N/A , 4x0.077€	4	BAT85, Schottky Rectifier
P1	N/A , 0.04€	1	1row,2pin, connector
P9	N/A , 0.072€	1	2row,14pin, connector
Q3	N/A , 0.081€	1	BC337,NPN transistor
R3	82Ω , 0.023€	1	1/4W resistor
R4	135Ω , 0.023€	1	1/4W resistor
R6	35kΩ , 0.1€	1	1/4W resistor
R7	73Ω , 0.045€	1	1/4W resistor
R25,R54	5.6Ω , 2x0.018€	2	1/4W resistor
R28,R29	680kΩ , 2x0.009€	2	1/4W resistor
R30,R31,R32,R33	10kΩ , 4x0.027€	4	1/4W resistor
R34,R35	1kΩ , 2x0.018€	2	1/4W resistor
R36,R37,R44,R45	100kΩ , 4x0.018€	4	1/4W resistor
R38	600Ω , 0.021€	1	1/4W resistor
R39	25kΩ , 0.063€	1	1/4W resistor
R41,R50,R51	47kΩ , 3x0.094€	3	1/4W resistor
R42	2kΩ , 0.036€	1	1/4W resistor
R43	120Ω , 0.018€	1	1/4W resistor
R46	10Ω , 0.036€	1	1/4W resistor
R49	16kΩ , 0.014€	1	1/4W resistor
R52,R53	1MΩ , 0.018€	2	1/4W resistor
S1 (various components)	N/A , 2x0.1€	1	This is 2x(1way,5pin header)
S2	N/A , 0.6€	1	This is 2way, 4pin header
IC1	N/A , 0.63€	1	555 timer, DIP
IC2	N/A , 2.21€	1	INA126, DIP
IC3	N/A , 0.56€	1	LM358
IC4	N/A , 0.44€	1	TL082CP, OPAMP, JFET
Total:	15.90€		

List of components for the Urbisnet 12V to 5V converter:

Designator	Value	Quantity	Comment
P1,P2, P3	N/A 3x0.04€	3	1way, 2pin header
VR1	N/A , 1.98€	1	TL2575, switching voltage regulator
C1	10µF 16V, 0.048€	1	Electrolytic capacitor
D1	N/A , 0.077€	1	BAT85, Schottky Rectifier
L1	330uH , 0.57€	1	Round coil, choke
C2	330µF 16V, 0.07€	1	Electrolytic capacitor
K1	N/A , 1.81€	1	Relay,TSC-112L3H, Tyco
Q1	N/A , 0.081€	1	BC337, NPN transistor
R1	120Ω , 0.018€	1	1/4W resistor
P4	N/A , 0.3€	1	1pin header, with bolt
Total:	5.07€		

Main components of the project:

Designator	Value	Quantity	Comment
Aarlogic C10/3	192,00 €	1	Round Solutions Aarlogic C10/3, ARM, GSM, GPS, sdcard, GPIO, MAC for ethernet
WL-330GE	45.90€	1	ASUS router/repeater/access point
Magnetic Antenna Multi Banb RG174	20,90 €	1	GSM / GPS antenna
Pigtail U.FL to SMA	3x10.95€	3	Connects the C10/3 board to the GPS and GSM antenna, to connect the WIFI antenna to the ASUS WL-330GE
Small Ethernet cable	1,00 €	1	To connect the WL-330GE to the Ethernet interface of the BASE board
Cable gland M16	2x0.3€	2	Cable glands used to hold the DC connector to the station and the wifi antenna
WIFI antenna	8,00 €	1	Wifi antenna 2.4GHz
HAMMOND-1455T2201BK-CASE, ALUMINIUM, 52X160X220MM	36,00 €	1	Aluminum box, for the station, has longitudinal holder to support the PCBS
JACK DC 2.5mm	2,00 €	1	JACK t connect the power supply
SHT25	30,00 €	1	Temperature and humidity sensor, sensirion
MICS-2611	6,00 €	1	Semiconductor oxide O_3 sensor
MICS-4514	5,00 €	1	Semiconductor oxide CO & NO_2 sensor

SO2-BF	??	1	Electrochemical cell SO_2 gas sensor
NDIR IRC A1	75,00 €	1	NDIR, CO_2 gas sensor, Alphasense
Total:	422.40€		

Cost of the Urbisnet Station: 512.29€