Advanced IOT Applications

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Lecture - 33
Introduction to air quality sensors

So, if the problem is so, well defined and the issues related to air quality as far as human health is also well known. Why has it not taken off, why is it that we are not able to do this large scale monitoring and take some action on it? That is the question that maybe bothering you ok. The reason why IOT too has not really succeeded in a great manner, I see possibilities happening now, but it is not happened till now several research projects have been launched.

The bug of air quality monitoring has caught several researchers over the years not at all with any success ok, no major success, you may ask why is this why is this a problem? Even, I have been trying personally in my lab for about a year now. And actually all what I am saying is from my experience of building systems and trying to do this monitoring of air quality.

So, please note I am going to show you something as well. So, its all about lab demonstrations and building systems and monitoring all that is essentially what, also I have been trying to do. I my personal opinion the reason why it has not succeeded at all till now is because of one major non-financial reason; one major non-financial reason and that is with respect to calibration.

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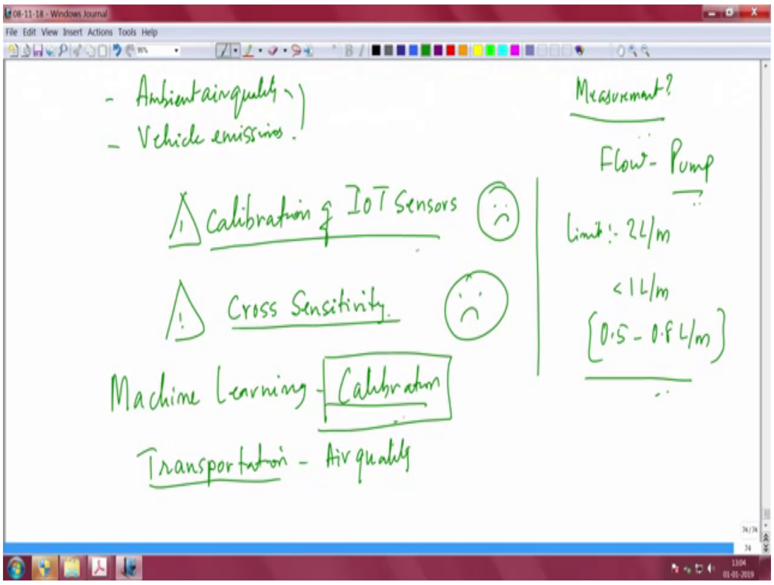

So, I will put down calibration of IoT sensors, this has been a problem. What you measure now is actually the same value if you measure it after that let us say a month or 2. So, this is one of the major problem.

So, calibration of IoT sensors are is an issue size has never been an issue; size of this IoT sensors has never been an issue. Making it into a small system and monitoring the gases has never been an issue, but calibration has become an issue. So, what is a typical size of these IoT sensors that you want to do, I will show you a board which you will get a feel.

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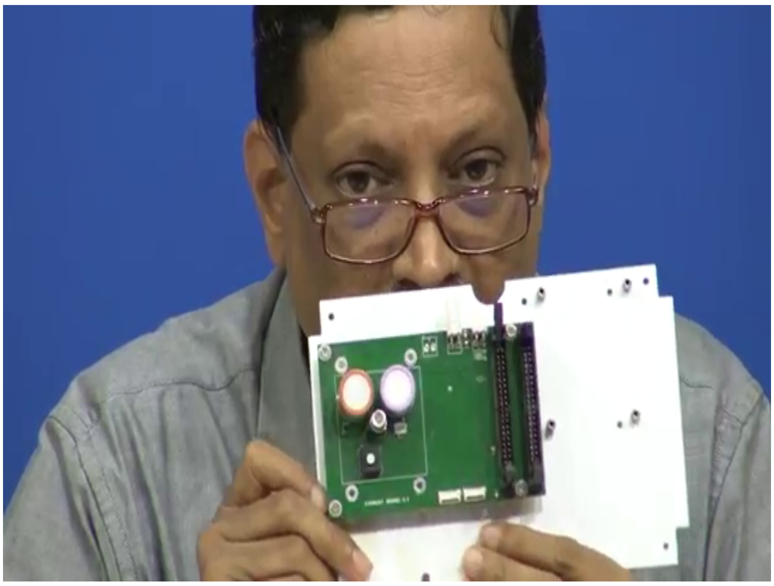

And this is a board you will see 2 3 of them in a cluster ok. Let me take show you these 3 1 2 and the one that this dot here, this 3 are sensors which are measuring you know different types of pollutants air pollutants. Size is not big actually the you can see that the diameter is a little over 1 centimetre about 1.5 centimetre or so and the height of these sensors is also close about 2 centimetre or so, not very big.

And you can see it is a small PCB and we can mount these sensors and start monitoring them, you also see 2 other sensors here right, you see this sensor here and this sensor here this one here, these are all 2 sensors.

These two are not so, big actually you can see that the size of an IC, we will have to go into the details of that and get into system design and so on. But, before we move one you must know that you have different type of sensor.

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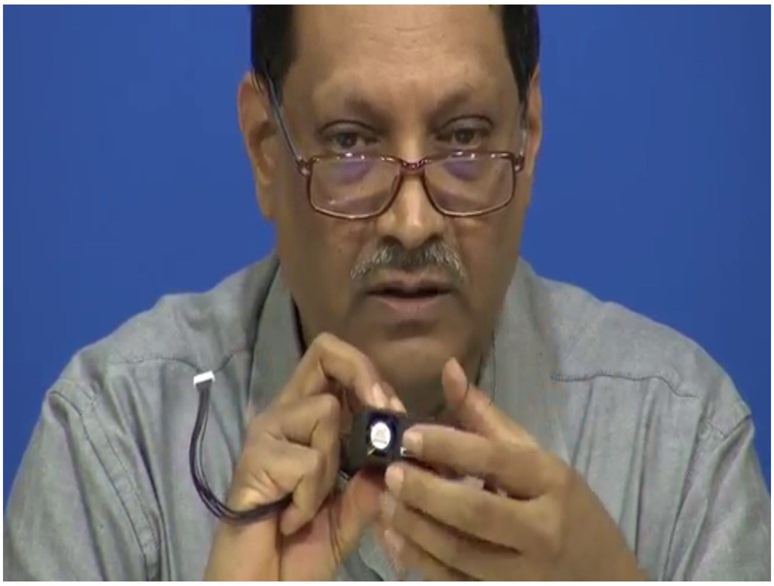

Not only these two I can also show you another little box here this little box, you see there is a fan here, there is a fan there is a fan here and if you apply voltage the fan will start rotating, it actually blows from here this fan is used for blowing out. So, it must be sucking something. So, it is essentially sucking from these bands and this is measuring the famous what we discussed now is the particulate matter.

So, this is a particulate matter sensor this is from honey well ok, this you can buy it at may be 1500 or 2000 rupees you can buy 1 and monitor both particulate matter 2.5 as well as particulate matter 10 and so on. So, essentially its not about size its not really about exorbitantly expensive and all that, its mostly because of one reason that is that the fact that these are hard to calibrate and keep the calibration on for months or if not years, I am going to keep them calibrated.

Also if you go back to these electrochemical sensor, they have certain amount of shelf life right. And you must find mechanisms to replace them periodically they are expensive, they are expensive compared to semiconductors sensors, they are very expensive, but when it comes to health you really do not worry about how expensive they are right.

To design a good system such that you know you measure it as accurately as possible so, keep the cost out of the mind do not worry about the cost because this is about health. So, maintaining a good calibration and ensuring that the sensors are responding or the response times are good fast and they are able to give you something in terms of being very accurate. To, what is happening in the ambient is where that real trick is about making IoT sensors a success monitoring air pollution with IoT sensors a big success. The second problem most of these sensors because of the way they are constructed, have another issue of cross sensitivity.

So, if you ask me the problems one is calibration the other is cross sensitivity. If you are; if you are sensitive to one gas which is based on oxidation you are also sensitive to another gas which is you know almost doing the same oxidation process. So, issues of being cross sensitive to other gases really is an issue, we will go into that details so, that is another thing.

So, how do you choose your sensors such that the cross sensitivity for other gases is minimised these you have to (Refer Time: 07:10). So, when you come to calibration of IoT sensors it is an issue cross sensitivity is also a not so a nice thing cost I am not going to put as I mentioned, but making them small compact is another thing.

Now, any measurement you want to do you want to do ok, any measurement you want to do with these sensors, these sensors cannot be placed in a corner of a room, you cannot say that ok. I want measure indoor air quality. So, I am going to take these sensor and put it one corner and let it make a measurement of what is the air quality in that that is not going to work; it requires a flow ok.

These sensors require a flow somehow you have to ensure that these sensors have a flow of air sample of air is picked and then it is and a measurement is made. So, how do you ensure flow is there, which means you have to pump, you have to suck the air in regulate it to whatever minimum required and then have an exhaust and then take them out ok. So, which means you need a flow and that means, if you want to maintain a flow you will definitely need a pump.

So, you have to put a small pump and again pump will require its own power which you have to supply. And you have to ensure that the flow does not exceed a certain numbers. See this is a dicey question people have said that the air flow should be greater than 2 litres per minute some people say this ok. So, limit this I will say is the limit, but typically when you do a measurement they do 1 litre per minute. And infact less than 1 litre per minute typical 0.5 to 0.8 litres per minute should be flowing across these senses.

So, in order to ensure that you do a proper measurements. So, this is another consideration. So, put an IoT product with maintaining this flow main ensuring that cross sensitivity, calibration of IoT sensors, all these means that this is really a very interesting and fertile area for system designers like us and course participants like you to get sensitize to develop very robust systems, which can do large scale special monitoring of air quality.

Now, I mentioned to an important point about that today the probability of an IoT sensor based system succeeding in accurately monitoring is a reality, because of this machine learning techniques ok; machine learning techniques for calibration ok. So, there is a wonderful paper which we were looking up from simple techniques statistical prediction techniques like linear regression, then multivariate regression and then moving onto artificial neural networks. And all of that which essentially are used in the air quality monitoring mostly for the purpose of calibration.

So, let us look up that paper and understand little bit about that paper and then come back to system design and then wind up in terms of a nice demonstration. I think that is the overall view that we should take in this little module. Before, we go on to looking up the paper which essentially talks about why the machine learning techniques are a sort of mitigation for problem of calibration? We should what are the parameters that a country like India has to keep measuring in terms of let us say the number of gases that had to be monitored. So, I will take you to a snapshot I looked up in on the central pollution control board ok.

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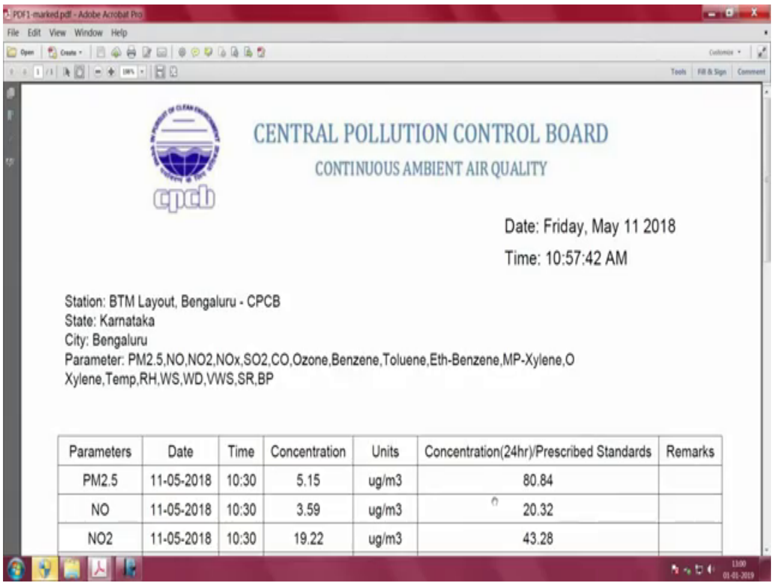

CENTRAL POLLUTION CONTROL BOARD

CONTINUOUS AMBIENT AIR QUALITY

Date: Friday, May 11 2018

Time: 10:57:42 AM

Station: BTM Layout, Bengaluru - CPCB
State: Karnataka
City: Bengaluru
Parameter: PM2.5,NO,NO2,NOx,SO2,CO,Ozone,Benzene,Toluene,Eth-Benzene,MP-Xylene,O Xylene,Temp,RH,WS,WD,VWS,SR,BP

Parameters	Date	Time	Concentration	Units	Concentration(24hr)/Prescribed Standards	Remarks
PM2.5	11-05-2018	10:30	5.15	ug/m3	80.84	
NO	11-05-2018	10:30	3.59	ug/m3	20.32	
NO2	11-05-2018	10:30	19.22	ug/m3	43.28	

This is you can see this is central pollution control board continuous ambient air quality monitoring in Bengaluru.

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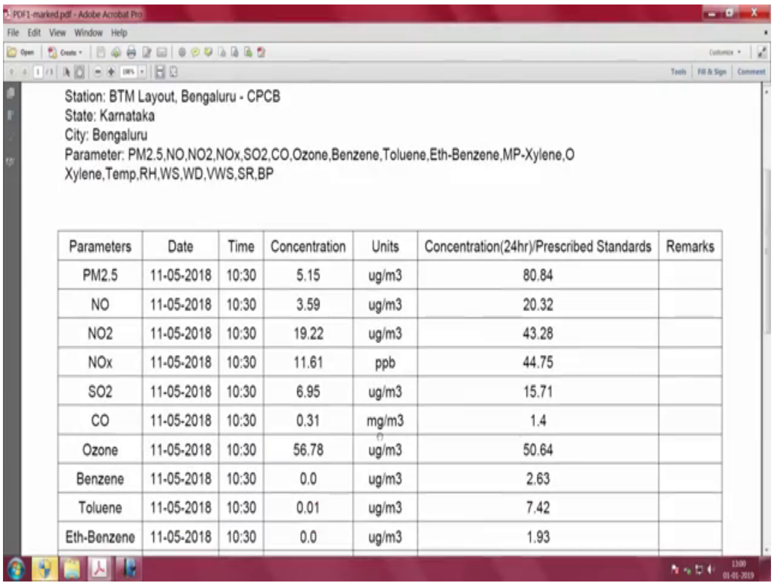

Station: BTM Layout, Bengaluru - CPCB
State: Karnataka
City: Bengaluru
Parameter: PM2.5,NO,NO2,NOx,SO2,CO,Ozone,Benzene,Toluene,Eth-Benzene,MP-Xylene,O Xylene,Temp,RH,WS,WD,VWS,SR,BP

Parameters	Date	Time	Concentration	Units	Concentration(24hr)/Prescribed Standards	Remarks
PM2.5	11-05-2018	10:30	5.15	ug/m3	80.84	
NO	11-05-2018	10:30	3.59	ug/m3	20.32	
NO2	11-05-2018	10:30	19.22	ug/m3	43.28	
NOx	11-05-2018	10:30	11.61	ppb	44.75	
SO2	11-05-2018	10:30	6.95	ug/m3	15.71	
CO	11-05-2018	10:30	0.31	mg/m3	1.4	
Ozone	11-05-2018	10:30	56.78	ug/m3	50.64	
Benzene	11-05-2018	10:30	0.0	ug/m3	2.63	
Toluene	11-05-2018	10:30	0.01	ug/m3	7.42	
Eth-Benzene	11-05-2018	10:30	0.0	ug/m3	1.93	

You can look up parameters that are monitored PM 2.5 nitric oxide, nitrogen dioxide, other NO x components, sulphur dioxide, carbon monoxide, ozone, benzene, toluene then Eth-Benzene, MP Xylene, O Xylene, temperature, relative humidity so on and so forth. Several other components are actually monitored.

So, typically a country like ours these are the parameters that governments setup very sophisticated equipment’s to measure these parameters. And these are typically done by the central pollution control board, you will see also that this numbers keep running in a continuous display also in airports, but this is telling you what is the level of air quality at that moment is also flash there. So, these are the important parameters.

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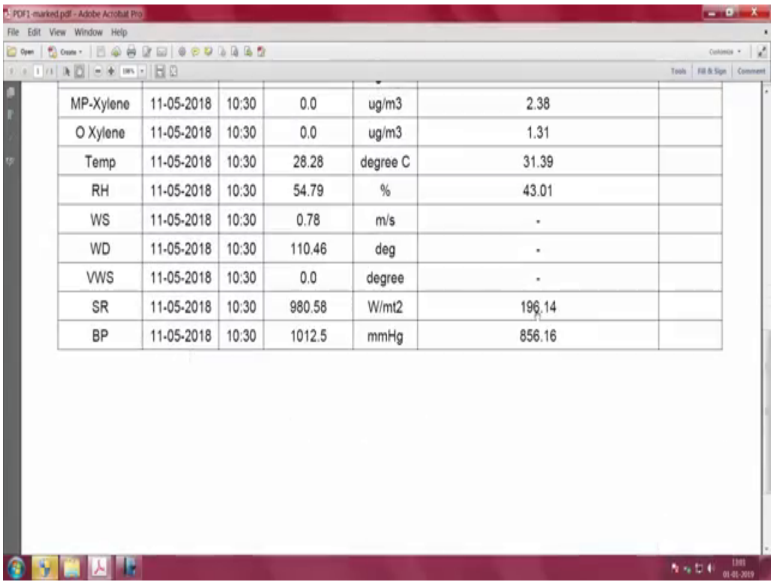

MP-Xylene	11-05-2018	10:30	0.0	ug/m3	2.38	
O Xylene	11-05-2018	10:30	0.0	ug/m3	1.31	
Temp	11-05-2018	10:30	28.28	degree C	31.39	
RH	11-05-2018	10:30	54.79	%	43.01	
WS	11-05-2018	10:30	0.78	m/s	-	
WD	11-05-2018	10:30	110.46	deg	-	
VWS	11-05-2018	10:30	0.0	degree	-	
SR	11-05-2018	10:30	980.58	W/mt2	196.14	
BP	11-05-2018	10:30	1012.5	mmHg	856.16	

So, if you look up central pollution control board, you will get a wealth of information and you can process based on the that wealth of information, what is the current pollution levels, concentration levels and if you know what is a prescribe standard limits, then you actually know how to compare. Look at PM 2.5 on May 5th 2018 in the morning at 10 30 or so, you will see that concentration over 24 hour our period was a 80.84 micrograms per metre cube.

Remember our safe limit is 40 from Indian standards perspective world health organisation is 10 microgram per metre cube and sensors that they have put in place is able to measure quite accurately. To show that it is about 80.84 roughly twice what the Indian standard actually prescribes.

So, like this you could read about other parameters as well note that sometimes nitric oxide, nitrogen dioxide, they could be mentioned either in terms of weight. Microgram per metre cube or they could also be mentioned in terms of parts per million parts per billion and so on. So, those are the other the parameters ok. So, you may now ask another question before we move on to calibration and all that.

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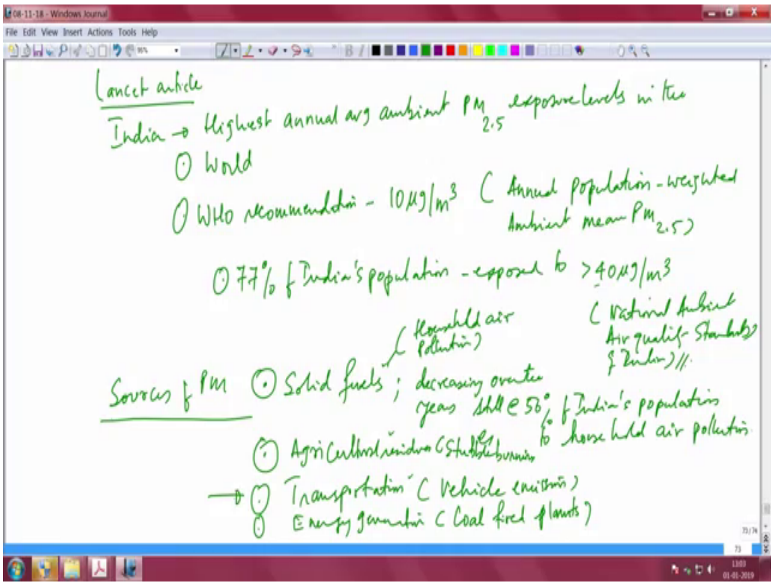

The other question is why should I study out of the parameters that we discussed the solid fuels agricultural residues, transportation, energy generation from coal fire and plants. Why would I want to worry about transportation? In fact, its a nice weeping boy in my opinion this transportation related things, transportation related air quality pollution several papers you will get air quality due to transportation, you will get several 100 and 100s of papers including my own lab.

Again looking at transportation as a cause for generation of air pollutants particularly particulate matter in the other paper you have seen that it was discussed. You may now ask why or why is everybody looking at that. For that I will show you the reason for that particular thing and here is indeed the paper which is talking about it.

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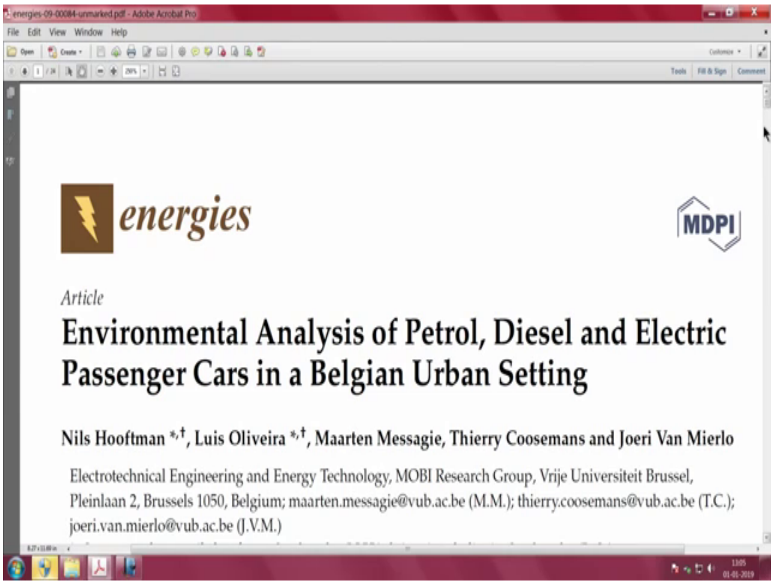

I should show you the title of this paper is environment analysis of petrol diesel and electric passenger cars in a Belgian urban setting. So, this is the paper and I was trying to read this paper, see essentially there is no textbook on this air quality I must tell you this. Its all about reading from different articles, different newspaper cuttings and going after some links that are available and piecing together to give cohesive understanding of what is happening.

So, essentially I have tired that only, there is no text book I have not (Refer Time: 15:45) any textbook and I thought that this is important because these are very current publication that have happened in the recent 1 2 years. So, its important for you to follow what is the actual things that are happening. So, please look up this paper you may be able to download this paper. And now let us go back and look at that one section of understanding why automotive is a weeping by equivalent for understanding the air quality ok. So, let me quickly come to the table and you will see that ok.

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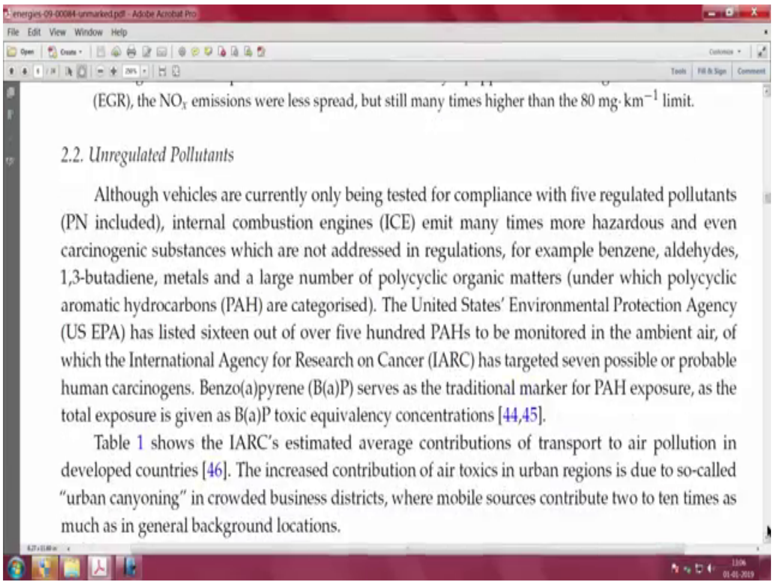
(EGR), the NO_x emissions were less spread, but still many times higher than the 80 mg·km^{-1} limit.

2.2. *Unregulated Pollutants*

Although vehicles are currently only being tested for compliance with five regulated pollutants (PN included), internal combustion engines (ICE) emit many times more hazardous and even carcinogenic substances which are not addressed in regulations, for example benzene, aldehydes, 1,3-butadiene, metals and a large number of polycyclic organic matters (under which polycyclic aromatic hydrocarbons (PAH) are categorised). The United States' Environmental Protection Agency (US EPA) has listed sixteen out of over five hundred PAHs to be monitored in the ambient air, of which the International Agency for Research on Cancer (IARC) has targeted seven possible or probable human carcinogens. Benzo(a)pyrene (B(a)P) serves as the traditional marker for PAH exposure, as the total exposure is given as B(a)P toxic equivalency concentrations [44,45].

Table 1 shows the IARC's estimated average contributions of transport to air pollution in developed countries [46]. The increased contribution of air toxics in urban regions is due to so-called "urban canyoning" in crowded business districts, where mobile sources contribute two to ten times as much as in general background locations.

So, I think its important to read all this. Although vehicles are currently only being tested in compliance with five regulated pollutants, internal combustion engines emit many times more hazardous and even carcinogenic substances which are addressed in regulations.

For example; benzene, aldehydes, 1 coma 3 butadiene, metals and large number of polycyclic organic matters under which Polycyclic Aromatic Hydrocarbons PAH are categorised. When, we talk about pollutant which are not even being discussed and they are just about these 5 regulated pollutants, but what about these un regulated pollutants and this is these are some examples. So, the United States environment protection agency has listed sixteen out of over five hundred polycyclic aromatic hydrocarbons to be monitored in the ambient air, of which the international agency for research on cancer has targeted it is seven possible or probable human carcinogens.

So, its cancer causing please note. Benzopyrene serves as the traditional marker for PAH exposure as the total exposure is given in some unit ok. Its called a toxic equivalency concentration you may have to go and lookup this reference for that.

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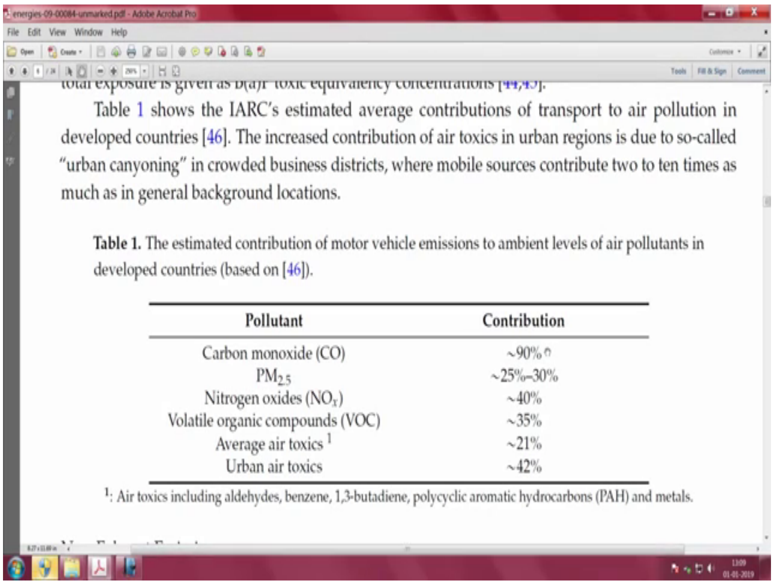

Table 1 shows the IARC's estimated average contributions of transport to air pollution in developed countries [46]. The increased contribution of air toxics in urban regions is due to so-called "urban canyoning" in crowded business districts, where mobile sources contribute two to ten times as much as in general background locations.

Table 1. The estimated contribution of motor vehicle emissions to ambient levels of air pollutants in developed countries (based on [46]).

Pollutant	Contribution
Carbon monoxide (CO)	~90%
$PM_{2.5}$	~25%–30%
Nitrogen oxides (NO_x)	~40%
Volatile organic compounds (VOC)	~35%
Average air toxics [1]	~21%
Urban air toxics	~42%

[1]: Air toxics including aldehydes, benzene, 1,3-butadiene, polycyclic aromatic hydrocarbons (PAH) and metals.

But, that is besides the point the table from this IARC which is the International Agency for Research on Cancer estimated average contributions of transport to air pollution in developed countries. And the increase contribution of air toxic in urban region is and all that have been shown and essential contribute to 2 to 10 times as much as in general background locations. So, here is why you have to understand the transportation as a major culprit for degradation in air quality. Carbon monoxide contribution to air quality is roughly 90 percent, PM 2.5 25 to 30 percent it is reasonable right.

Because, we know that there are other contributing factors which we listed can also be sources for P M. So, this is another source and this is restricted about 25 to 30 percent. Nitrogen oxides 40 percent is the contribution, volatile organic compounds 35 percent, average air toxics 21 percent and urban air toxic about 42 percents. So, when you talk about talk about air toxics you talk about aldehydes Benzyne 13 butadiene PH and metals ok, so, these are very very important.

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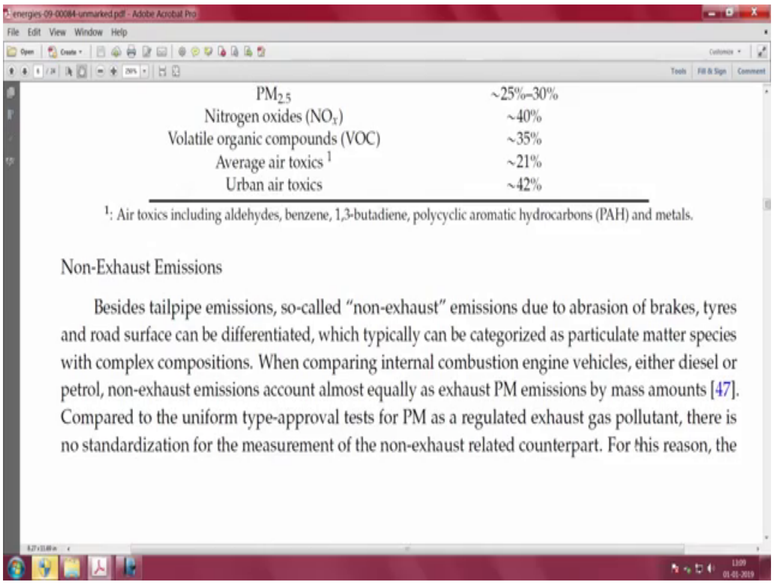

So, here is another twist to why vehicular emissions you have to read you have to understand and it comes in a very counter intuitive way and this is true for any vehicle ok. And that is what is called non exhaust emission, nothing coming from exhaust, nothing because of any fossil fuel burning and all that, just because the vehicles moves it is creating a lot of particulate matter and that is what you see here.

Beside tail pipe emissions, so called "non-exhaust" emissions due to breaks abrasion of breaks, tyres and road surface can be differentiated, which typically can be categorised as particulate matter species with complex compositions. When comparing internal combustion engine vehicles, either diesel or petrol, non exhaust emissions account almost equally as exhaust particulate matter emissions by mass amounts. Compared to the uniform type approval test for PM as a regulated exhaust gas pollutant, there is no standardization for the measurement of non-exhaust related counterpart.

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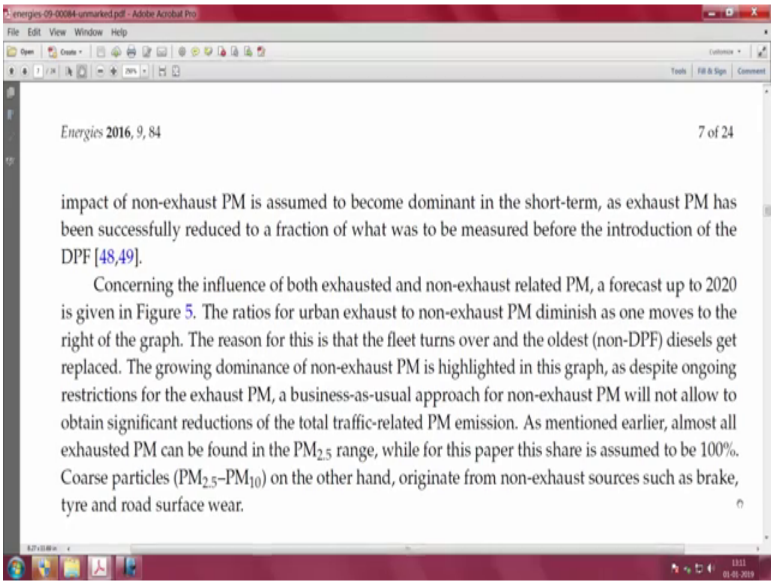

That an eye opener right that an eye opener ok and concerning the influence of both exhausted and non-exhaust particulate matter a forecast up to 20 is given in figure 5 let us lookup figure 5; so, here is figure 5.

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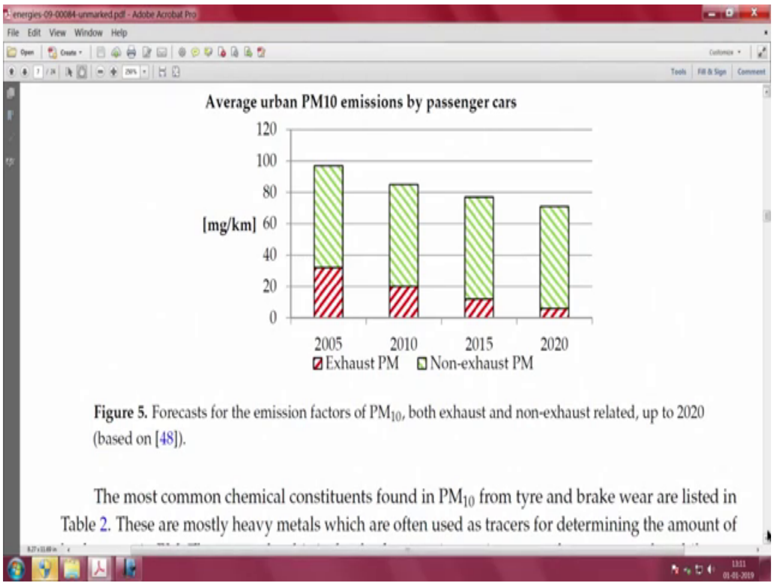

. You have exhaust and non-exhaust, you can see the contribution of non-exhaust has been significant and you can see this part coming down which is already positive news. So, lot of vehicle manufacturers are putting efforts to get down the particulate matter due to exhaust, due to burning, due to fossil fuels, but this component is going up and this is unregulated, that is really the problem.

Why is this a problem they refer to the reason for this is that fleet turns over and oldest diesels get replaced the growing dominance of non-exhaust particulate matter is highlighted in this graph. As despite on-going restrictions for the exhaust PM a business as usual approach for non-exhaust PM will not allow to obtain significant reduction of the total traffic related PM emission.

As mentioned earlier almost all exhausted PM can be found in PM 2.5 range, while for this paper this share is assumed to be 100 percent. Coarse particles on the other hand, originate from non exhaust sources such as brake, tyre and road surface wear and all that.

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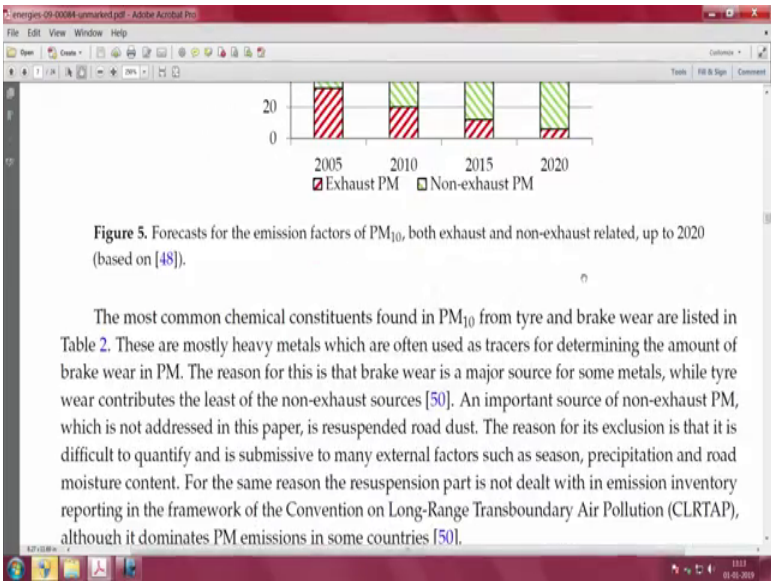

So, please note that this is also a very important thing as far as air quality monitoring is concerned.

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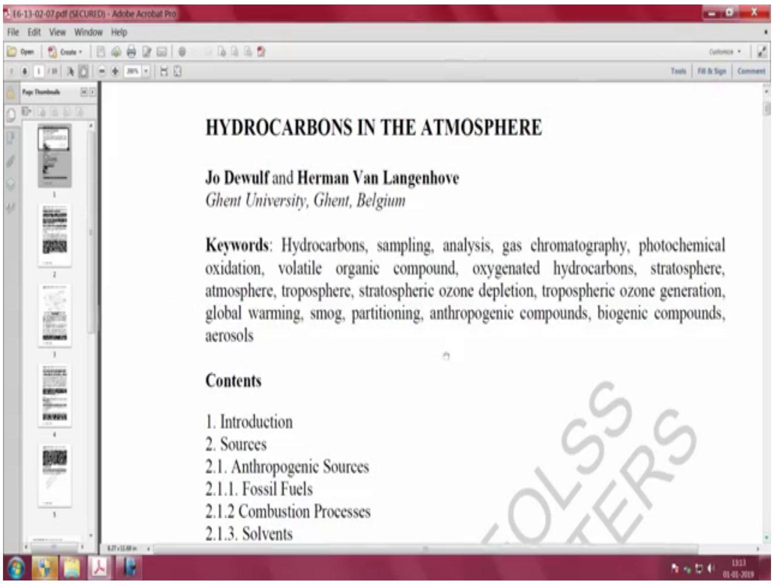

Finally, before we even dwell into anything useful you must know something about the issue related to hydrocarbons ok. So, I thought, I will just spend some time on hydrocarbons and then we will move on with the final aspects of how to make air quality monitoring, a lot more successful ok.

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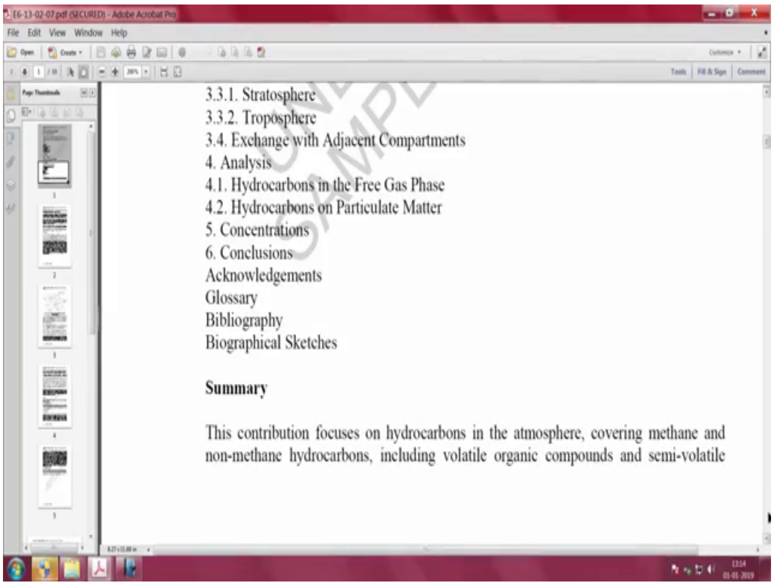

So, you may want to know what is volatile organic compounds and what is non-volatile? This paper is actually talking about that.

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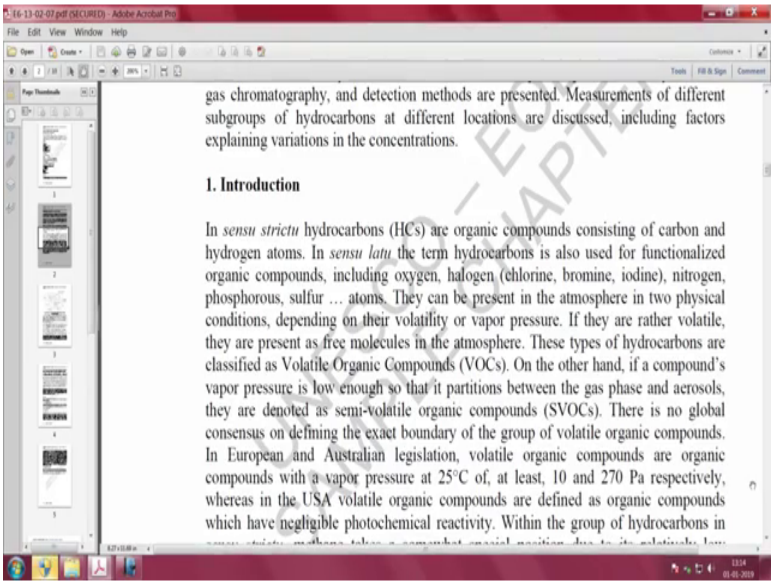
gas chromatography, and detection methods are presented. Measurements of different subgroups of hydrocarbons at different locations are discussed, including factors explaining variations in the concentrations.

1. Introduction

In *sensu strictu* hydrocarbons (HCs) are organic compounds consisting of carbon and hydrogen atoms. In *sensu latu* the term hydrocarbons is also used for functionalized organic compounds, including oxygen, halogen (chlorine, bromine, iodine), nitrogen, phosphorous, sulfur … atoms. They can be present in the atmosphere in two physical conditions, depending on their volatility or vapor pressure. If they are rather volatile, they are present as free molecules in the atmosphere. These types of hydrocarbons are classified as Volatile Organic Compounds (VOCs). On the other hand, if a compound's vapor pressure is low enough so that it partitions between the gas phase and aerosols, they are denoted as semi-volatile organic compounds (SVOCs). There is no global consensus on defining the exact boundary of the group of volatile organic compounds. In European and Australian legislation, volatile organic compounds are organic compounds with a vapor pressure at 25°C of, at least, 10 and 270 Pa respectively, whereas in the USA volatile organic compounds are defined as organic compounds which have negligible photochemical reactivity. Within the group of hydrocarbons in

So, let us see what exactly one means by this definition its a little bit into chemistry, but its absolutely important you know about it ok. Essentially, when you talk about hydrocarbons, you are talking about organic compounds which are typically carbon and hydrogen right. And this term hydrocarbon is also used for functionalized organic compound including oxygen, halogen, nitrogen, phosphorous, sulphur atoms and all that. Basically it the definition comes from the fact that talk about from the volatility of or vapour pressure of these compounds.

So, you can see that VOC or SVOC when you say the VOC is essentially are hydrocarbons classified as VOC which means their vapour pressure must be very high. And, you can say the vapour pressure if it is low so, that it partitions between gas phase and aerosols, they then you call them SVOCs. So, they are called Semi Volatile Organic Compounds.

There is no global consensus on defining the exact boundary between them, but typically if you talk about organic compounds with a vapour pressure at 25 degrees of at least 10 and 270 respectively, where as in USA volatile organic compounds are defined as, organic compounds which have negligible photo chemical reactivity.

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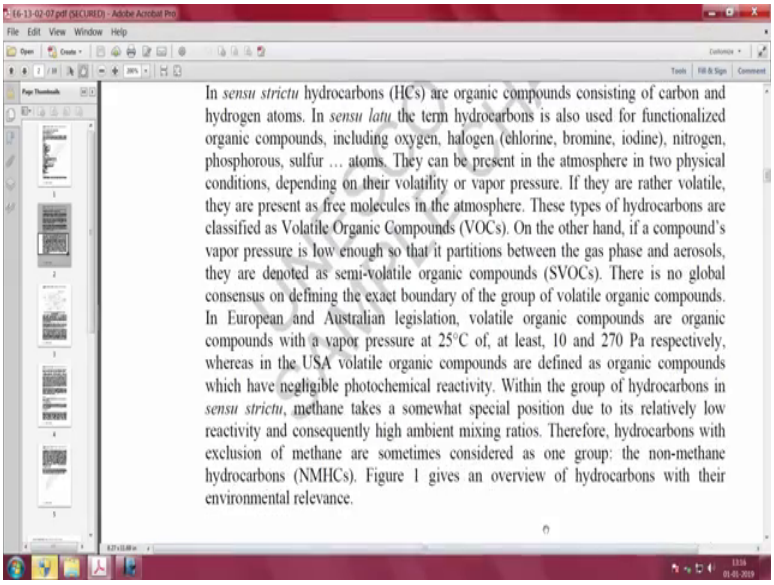

But, whatever be the case there are these group of hydrocarbon in this group of hydrocarbons methane is something that is somewhat special, you pull it out because it has a special position due to its relatively low reactivity and consequently high ambient mixing ratios ok. Therefore, hydrocarbons with exclusion of methane are sometimes considered as one group; the non-methane hydrocarbons and therefore, you will see a figure with their environmental relevance.

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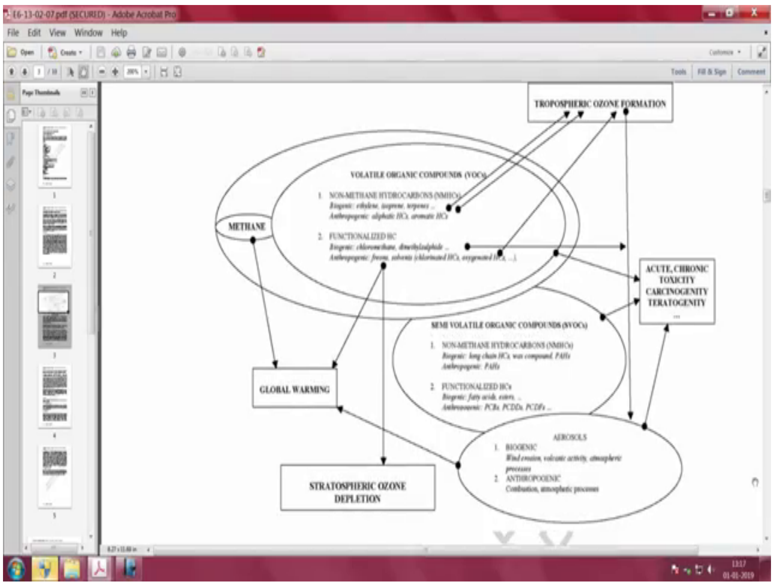

So, let us see this you can see methane is out contributing to global warming, then why you have tropospheric ozone formation, then acute chronic toxicity carcinogenicity and teratogenity, you can see these are all about SVOCs.

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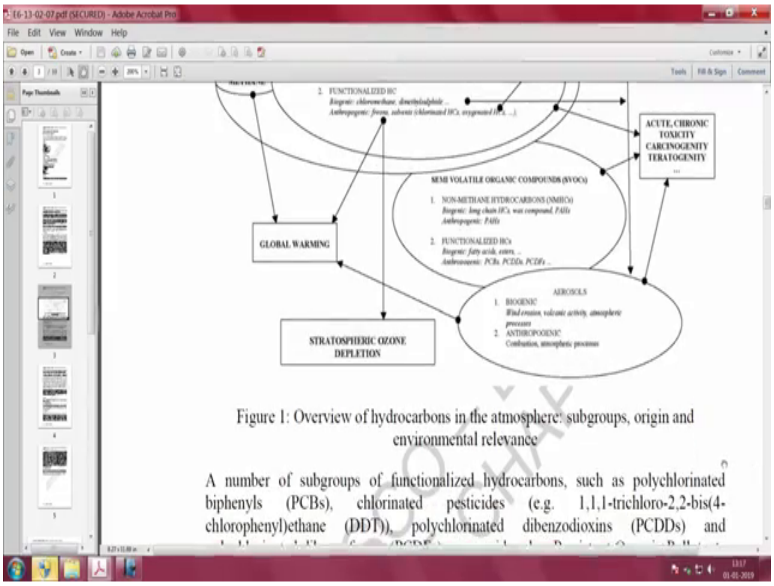

So, its a nice over view of hydrocarbons in the atmosphere subgroups origin and all that.

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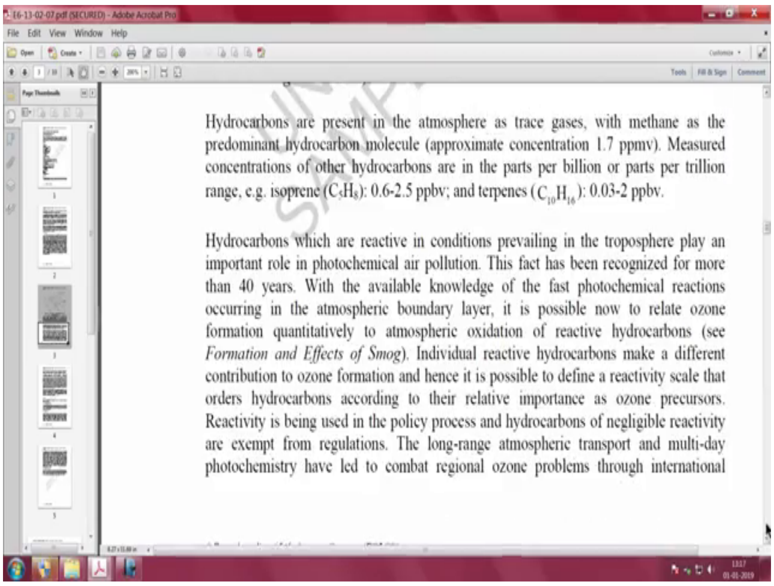

So, it will be good if you could also read this paper and understand a little more about hydrocarbons and also the reason why you need to measure them quite accurately.

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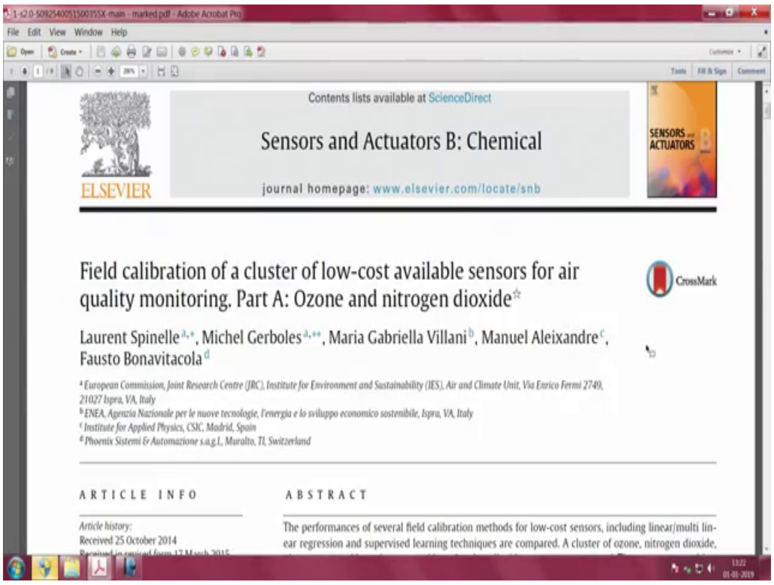
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Field calibration of a cluster of low-cost available sensors for air quality monitoring. Part A: Ozone and nitrogen dioxide☆

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ABSTRACT

The performances of several field calibration methods for low-cost sensors, including linear/multi linear regression and supervised learning techniques are compared. A cluster of ozone, nitrogen dioxide,

So, I mention to you that currently there is a good success there is a possibility of a good success if one makes a IoT system, builds an IoT system for large scale special monitoring. Because, current machine learning tools are becoming popular for the purposes of calibration of this IoT sensors. I was recently an article and I thought I will point you to this article with appeared in Elsevier Sensors and Actuators. The article is called field calibration of a cluster of low cost available sensors for air quality monitoring, essential is talking about part a which is ozone and nitrogen dioxide.

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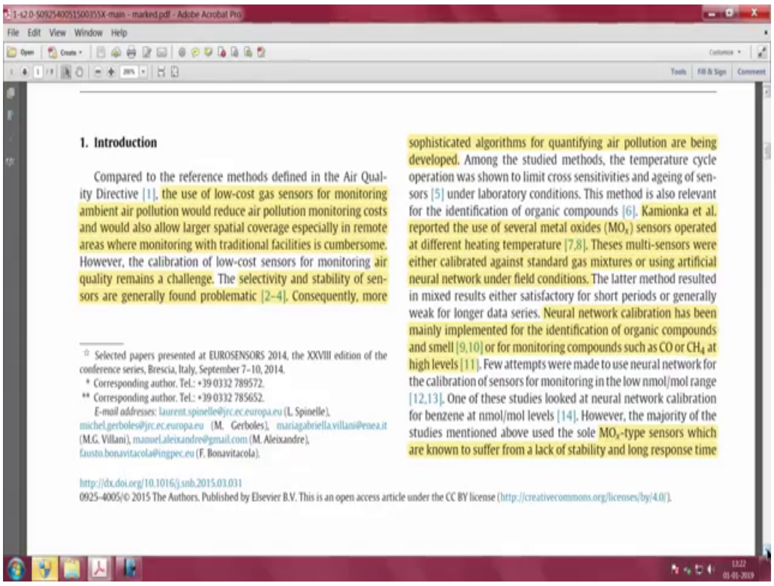
1. Introduction

Compared to the reference methods defined in the Air Quality Directive [1], the use of low-cost gas sensors for monitoring ambient air pollution would reduce air pollution monitoring costs and would also allow larger spatial coverage especially in remote areas where monitoring with traditional facilities is cumbersome. However, the calibration of low-cost sensors for monitoring air quality remains a challenge. The selectivity and stability of sensors are generally found problematic [2–4]. Consequently, more sophisticated algorithms for quantifying air pollution are being developed. Among the studied methods, the temperature cycle operation was shown to limit cross sensitivities and ageing of sensors [5] under laboratory conditions. This method is also relevant for the identification of organic compounds [6]. Kamionka et al. reported the use of several metal oxides (MO_x) sensors operated at different heating temperature [7,8]. Theses multi-sensors were either calibrated against standard gas mixtures or using artificial neural network under field conditions. The latter method resulted in mixed results either satisfactory for short periods or generally weak for longer data series. Neural network calibration has been mainly implemented for the identification of organic compounds and smell [9,10] or for monitoring compounds such as CO or CH_4 at high levels [11]. Few attempts were made to use neural network for the calibration of sensors for monitoring in the low nmol/mol range [12,13]. One of these studies looked at neural network calibration for benzene at nmol/mol levels [14]. However, the majority of the studies mentioned above used the sole MO_x-type sensors which are known to suffer from a lack of stability and long response time

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So, let us see and what are the simple tools one may use to get a big picture of this problem related to calibration. The use of low cost gas sensor for monitoring ambient air quality would reduce air pollution monitoring cause and all that. So, you can have larger spatial area coverage especially in remote areas where monitoring with traditional facilities is cumbersome. So, he mentions about air quality monitoring is a challenge because selectivity and stability of sensors are generally found problematic, consequently more sophisticated algorithm for quantifying air pollution are being developed.

So, this is the trick that you could apply you have to apply your ingenuity in coming up with different type of algorithms essentially calibration of the sensors. Now, you can see that this sentence here is actually talking about a metal oxide semiconductor sensors several metal oxide sensors operated at different heating temperatures. These multi sensor where either calibrated again standard gas mixtures or using artificial neural networks under field conditions. Neural networks calibration has been mainly implemented in the identification of organic compounds and smell or for monitoring compound such as CO or CH 4, which is carbon monoxide or methane at high level.

So, neural network has been applied here. Whereas, the MO x sensors metal oxide semiconductor, sensor type sensors are known to suffer from lack of stability and long response time. They have a very long response time.

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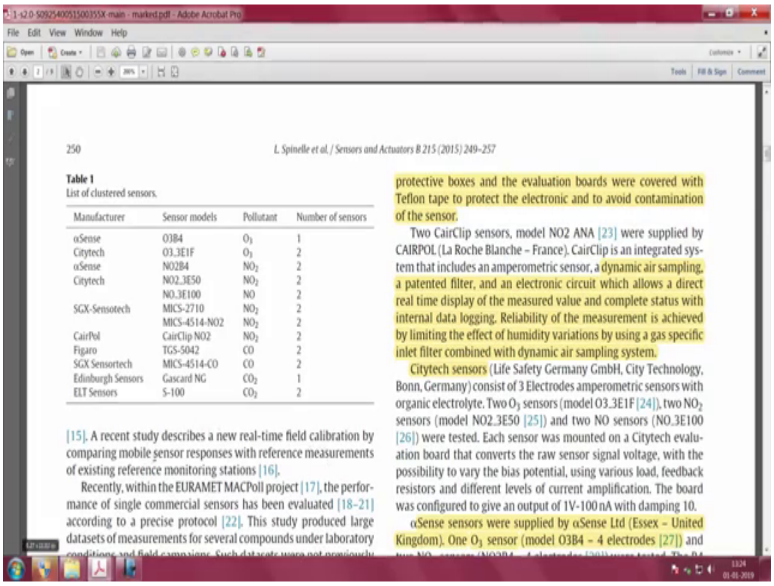

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Table 1
List of clustered sensors.

Manufacturer	Sensor models	Pollutant	Number of sensors
αSense	O3B4	O_3	1
Citytech	O3.3E1F	O_3	2
αSense	NO2B4	NO_2	2
Citytech	NO2.3E50	NO_2	2
	NO.3E100	NO	2
SGX-Sensotech	MICS-2710	NO_2	2
	MICS-4514-NO2	NO_2	2
CairPol	CairClip NO2	NO_2	2
Figaro	TGS-5042	CO	2
SGX Sensortech	MICS-4514-CO	CO	2
Edinburgh Sensors	Gascard NG	CO_2	1
ELT Sensors	S-100	CO_2	2

[15]. A recent study describes a new real-time field calibration by comparing mobile sensor responses with reference measurements of existing reference monitoring stations [16].

Recently, within the EURAMET MACPoll project [17], the performance of single commercial sensors has been evaluated [18–21] according to a precise protocol [22]. This study produced large datasets of measurements for several compounds under laboratory

protective boxes and the evaluation boards were covered with Teflon tape to protect the electronic and to avoid contamination of the sensor.

Two CairClip sensors, model NO2 ANA [23] were supplied by CAIRPOL (La Roche Blanche – France). CairClip is an integrated system that includes an amperometric sensor, a dynamic air sampling, a patented filter, and an electronic circuit which allows a direct real time display of the measured value and complete status with internal data logging. Reliability of the measurement is achieved by limiting the effect of humidity variations by using a gas specific inlet filter combined with dynamic air sampling system.

Citytech sensors (Life Safety Germany GmbH, City Technology, Bonn, Germany) consist of 3 Electrodes amperometric sensors with organic electrolyte. Two O_3 sensors (model O3.3E1F [24]), two NO_2 sensors (model NO2.3E50 [25]) and two NO sensors (NO.3E100 [26]) were tested. Each sensor was mounted on a Citytech evaluation board that converts the raw sensor signal voltage, with the possibility to vary the bias potential, using various load, feedback resistors and different levels of current amplification. The board was configured to give an output of 1V-100 nA with damping 10.

αSense sensors were supplied by αSense Ltd (Essex – United Kingdom). One O_3 sensor (model O3B4 – 4 electrodes [27]) and

So, you may have to do something else right, in order to calibrate them successfully. Recent study describes a new real time field calibration by comparing mobile sensor responses with reference measurements of existing reference monitoring stations have coming up. So, there are lot of interesting intelligent applications which are being done.

And this paper brings us to a very interesting table of what is clustered sensors are all about; you can see the names of the senses. Let me again expand if you want experiment you may want to choose these sensors because these are things which have been studied. There is a manufacturer called alpha sense and its measuring a pollutant like ozone, Citytech alpha sense for NO 2, again Citytech, SGX-Sensotech, which has a sensor model called mix 2710 mix 4514 for NO 2 ok.

So, how many they put into the study is interesting, then there is other company Cairpol there is Figaro TGS 5040 for carbon monoxide, SGX sensor tech MICS 4514 for carbon monoxide and Edinburgh sensors model called gas card for CO 2 ELT sensors and so on. So, you can see as this issue of multiple gases for the same sensor is evident take MICS 4514, you can see MICS 4514, you can measure carbon mono oxide, as well as you can also measure, nitrogen dioxide both from the same sensor.

You can see that you will have 2 sensing element; one takes care of oxidation, the other takes care of reduction and in the process able to measure on the same sensor both these parameters. But, you know you also have to take care of several issues before you start actually making a measurement there and we will discuss some of those issues in building such systems so, that you get a clear idea.

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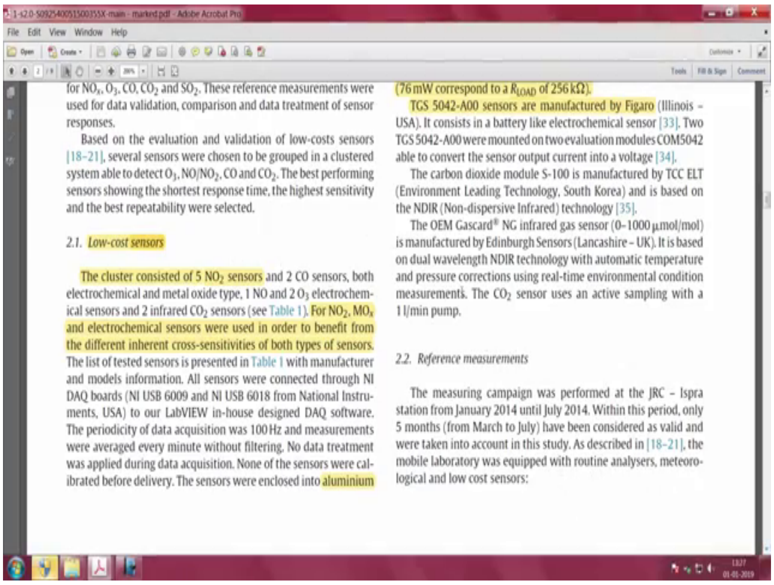

for NO_x, O_3, CO, CO_2 and SO_2. These reference measurements were used for data validation, comparison and data treatment of sensor responses.

Based on the evaluation and validation of low-costs sensors [18–21], several sensors were chosen to be grouped in a clustered system able to detect O_3, NO/NO_2, CO and CO_2. The best performing sensors showing the shortest response time, the highest sensitivity and the best repeatability were selected.

2.1. *Low-cost sensors*

The cluster consisted of 5 NO_2 sensors and 2 CO sensors, both electrochemical and metal oxide type, 1 NO and 2 O_3 electrochemical sensors and 2 infrared CO_2 sensors (see Table 1). For NO_2, MO_x and electrochemical sensors were used in order to benefit from the different inherent cross-sensitivities of both types of sensors. The list of tested sensors is presented in Table 1 with manufacturer and models information. All sensors were connected through NI DAQ boards (NI USB 6009 and NI USB 6018 from National Instruments, USA) to our LabVIEW in-house designed DAQ software. The periodicity of data acquisition was 100 Hz and measurements were averaged every minute without filtering. No data treatment was applied during data acquisition. None of the sensors were calibrated before delivery. The sensors were enclosed into aluminium

(76 mW correspond to a R_{LOAD} of 256 kΩ).

TGS 5042-A00 sensors are manufactured by Figaro (Illinois – USA). It consists in a battery like electrochemical sensor [33]. Two TGS 5042-A00 were mounted on two evaluation modules COM5042 able to convert the sensor output current into a voltage [34].

The carbon dioxide module S-100 is manufactured by TCC ELT (Environment Leading Technology, South Korea) and is based on the NDIR (Non-dispersive Infrared) technology [35].

The OEM Gascard® NG infrared gas sensor (0–1000 μmol/mol) is manufactured by Edinburgh Sensors (Lancashire – UK). It is based on dual wavelength NDIR technology with automatic temperature and pressure corrections using real-time environmental condition measurements. The CO_2 sensor uses an active sampling with a 1 l/min pump.

2.2. *Reference measurements*

The measuring campaign was performed at the JRC – Ispra station from January 2014 until July 2014. Within this period, only 5 months (from March to July) have been considered as valid and were taken into account in this study. As described in [18–21], the mobile laboratory was equipped with routine analysers, meteorological and low cost sensors:

So, we will move on. So, you can see this article will tell you also about this will give you an overview of these low cost sensors, you can see that they have chosen the sensor switch which from the table which I mentioned to you. And in this you can see that its clearly highlighted the problem of cross sensitivity right, its out here.

The cluster comprised or consisted of 5 NO 2 for NO 2 and comma MO x for the measurement of nitrogen dioxide, both semiconductor sensor as well as electrochemical sensors were used. In order to benefit from different inherent cross sensitivities of both types of sensor, whether you take electrochemical or the other way both of them suffer from cross sensitivity. It’s important you have to make enough noise about understanding where the problems are coming for measurement.

So, as I said the cross sensitivity calibration have been major bottlenecks for IoT to succeed in the measurement of these parameters. So, another important point is that the reason I marked it here is also important, whenever you do system design you have to ensure that you avoid contamination of the sensor. So, sensor measuring gases and you do not want them to be contaminated and make them sluggish.

So, ensure that their clean when they are making a measurement. So, they put some Teflon tape to protect the electronic and to avoid contamination of these sensors. So, the other thing that I know people have tried to you know sort of go ahead to sort of prepare a smart electronic circuits, which will display in real time the measured value as well as the complete internal data logging from within the system.

So, people have used very normal techniques to do that another thing that can you bring down the reliability of the measurement is the effect of humidity variations, you can see that you know humidity variations by using a gas specific inlet filter combined with dynamic air sampling system. All this smart electronic systems which remove humidity will also improve not only the lifetime of the sensor. But, also improves the reliability of measurement, alpha sensors is another company and you can look up alpha sensors also quite popular for in application in IoT.

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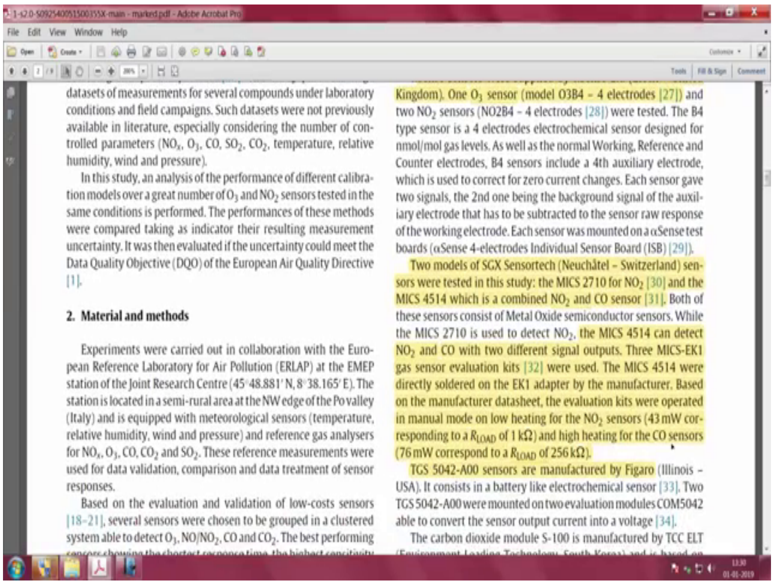
datasets of measurements for several compounds under laboratory conditions and field campaigns. Such datasets were not previously available in literature, especially considering the number of controlled parameters (NO_x, O_3, CO, SO_2, CO_2, temperature, relative humidity, wind and pressure).

In this study, an analysis of the performance of different calibration models over a great number of O_3 and NO_2 sensors tested in the same conditions is performed. The performances of these methods were compared taking as indicator their resulting measurement uncertainty. It was then evaluated if the uncertainty could meet the Data Quality Objective (DQO) of the European Air Quality Directive [1].

2. Material and methods

Experiments were carried out in collaboration with the European Reference Laboratory for Air Pollution (ERLAP) at the EMEP station of the Joint Research Centre (45°48.881′ N, 8°38.165′ E). The station is located in a semi-rural area at the NW edge of the Po valley (Italy) and is equipped with meteorological sensors (temperature, relative humidity, wind and pressure) and reference gas analysers for NO_x, O_3, CO, CO_2 and SO_2. These reference measurements were used for data validation, comparison and data treatment of sensor responses.

Based on the evaluation and validation of low-costs sensors [18–21], several sensors were chosen to be grouped in a clustered system able to detect O_3, NO/NO_2, CO and CO_2. The best performing

Kingdom). One O_3 sensor (model O3B4 – 4 electrodes [27]) and two NO_2 sensors (NO2B4 – 4 electrodes [28]) were tested. The B4 type sensor is a 4 electrodes electrochemical sensor designed for nmol/mol gas levels. As well as the normal Working, Reference and Counter electrodes, B4 sensors include a 4th auxiliary electrode, which is used to correct for zero current changes. Each sensor gave two signals, the 2nd one being the background signal of the auxiliary electrode that has to be subtracted to the sensor raw response of the working electrode. Each sensor was mounted on a αSense test boards (αSense 4-electrodes Individual Sensor Board (ISB) [29]).

Two models of SGX Sensortech (Neuchâtel – Switzerland) sensors were tested in this study: the MICS 2710 for NO_2 [30] and the MICS 4514 which is a combined NO_2 and CO sensor [31]. Both of these sensors consist of Metal Oxide semiconductor sensors. While the MICS 2710 is used to detect NO_2, the MICS 4514 can detect NO_2 and CO with two different signal outputs. Three MICS-EK1 gas sensor evaluation kits [32] were used. The MICS 4514 were directly soldered on the EK1 adapter by the manufacturer. Based on the manufacturer datasheet, the evaluation kits were operated in manual mode on low heating for the NO_2 sensors (43 mW corresponding to a R_{LOAD} of 1 kΩ) and high heating for the CO sensors (76 mW correspond to a R_{LOAD} of 256 kΩ).

TGS 5042-A00 sensors are manufactured by Figaro (Illinois – USA). It consists in a battery like electrochemical sensor [33]. Two TGS 5042-A00 were mounted on two evaluation modules COM5042 able to convert the sensor output current into a voltage [34].

The carbon dioxide module S-100 is manufactured by TCC ELT

Then of course, SGX Sensotech we will go into little detail here, you could use MICS 4514 which has combined no 2 and CO sensor and you can start measuring both ok. You can detect NO 2 and CO with 2 different signal output and you can use a evaluation kit which is available from sensor tech directly if you want to make measurements.

Now, it brings us to a very important sentence here, which sort of lays the emphasis for all measurements read this line very carefully. The MICS 4514, where directly soldered on the EK 1 adopted by the manufacturer trivial. Based on the manufacturer data sheet the evaluation kids wear operated in manual mode on low heating for NO 2 sensors 43 milli watt corresponding to a R load of 1 kilo ohm and high heating for CMOS sensor 76 milli watt corresponding to R load of 256 kilo ohm.

So, you can see that several things are packed into this sentence clearly if you want to make a measurement of any air pollutant in a semiconductor sensor, you have to heat the sensible need a heater. So, there will be a heating element and you heat it and you pass power different powers, in order to send the pollutant of interest. You heat it to some level, if you want to make a measurement heat the heater is taken to a different you pass a different power for a lower power for NO 2 measurement and higher power for measurement of carbon monoxide right.

So, that is what it is saying. And it is saying also for electronic engineers like us that the there is a change in R value, which is indicated by the concentration of the pollutant essentially R means resistors value. So, this is another thing that is coming out from this. So, most semiconductor sensors will show you change in concentration of level based on purely on the change in the resistance value. So, this is another important point that comes into our mind. So, we will discuss this, but keep this in your mind.

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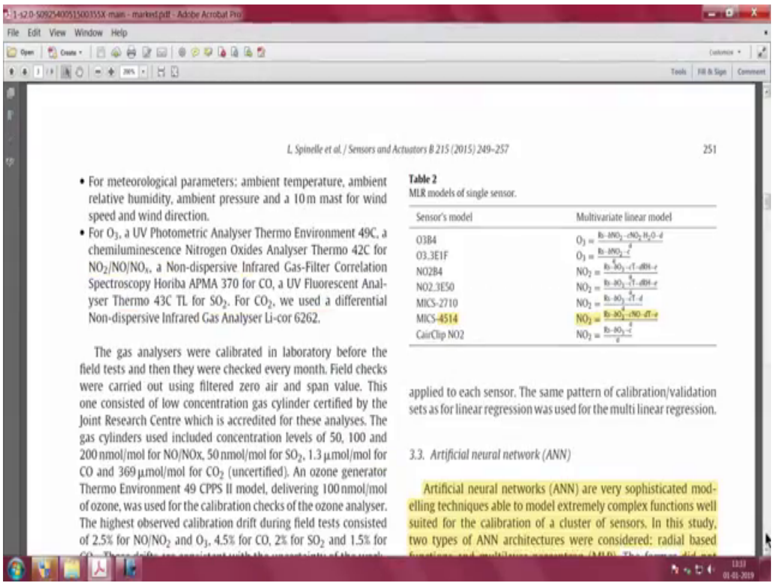

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- For meteorological parameters: ambient temperature, ambient relative humidity, ambient pressure and a 10 m mast for wind speed and wind direction.
- For O_3, a UV Photometric Analyser Thermo Environment 49C, a chemiluminescence Nitrogen Oxides Analyser Thermo 42C for $NO_2/NO/NO_x$, a Non-dispersive Infrared Gas-Filter Correlation Spectroscopy Horiba APMA 370 for CO, a UV Fluorescent Analyser Thermo 43C TL for SO_2. For CO_2, we used a differential Non-dispersive Infrared Gas Analyser Li-cor 6262.

The gas analysers were calibrated in laboratory before the field tests and then they were checked every month. Field checks were carried out using filtered zero air and span value. This one consisted of low concentration gas cylinder certified by the Joint Research Centre which is accredited for these analyses. The gas cylinders used included concentration levels of 50, 100 and 200 nmol/mol for NO/NOx, 50 nmol/mol for SO_2, 1.3 µmol/mol for CO and 369 µmol/mol for CO_2 (uncertified). An ozone generator Thermo Environment 49 CPPS II model, delivering 100 nmol/mol of ozone, was used for the calibration checks of the ozone analyser. The highest observed calibration drift during field tests consisted of 2.5% for NO/NO_2 and O_3, 4.5% for CO, 2% for SO_2 and 1.5% for

Table 2
MLR models of single sensor.

Sensor's model	Multivariate linear model
O3B4	$O_3 =$ [illegible]
O3.3E1F	$O_3 =$ [illegible]
NO2B4	$NO_2 =$ [illegible]
NO2.3E50	$NO_2 =$ [illegible]
MICS-2710	$NO_2 =$ [illegible]
MICS-4514	$NO_2 =$ [illegible]
CairClip NO2	$NO_2 =$ [illegible]

applied to each sensor. The same pattern of calibration/validation sets as for linear regression was used for the multi linear regression.

3.3. Artificial neural network (ANN)

Artificial neural networks (ANN) are very sophisticated modelling techniques able to model extremely complex functions well suited for the calibration of a cluster of sensors. In this study, two types of ANN architectures were considered: radial based

Then there is another company called Figaro that is also a low cost sensor this paper is talking about calibration methods which we can discuss in a little more in detail.

Thank you very much.