Advanced IOT Applications

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Lecture – 39
Air quality: Real time measurement for a drive cycle

So, let us see a demonstration of our Air quality project we have been associated. This project is jointly researched by a colleague of mine by name Doctor Chandramani Singh and myself we are involved in this project. It is a 1 year project, we are doing this for a company which is in the automotive business. And this project has a able support from a 4 project staff Abhishek, Sachin, Prajwal and Harish all four of them and you will see a few things about this project which perhaps is a system building exercise.

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Now, let me show you a few small things. This is the car of interest that we want to measure some amount of pollution that is coming from not just the exhaust pipe which you can see here we have an exhaust pipe essentially emitting a lot of hot gases and the hot gases have to be cooled down to specified levels so that IoT sensors can essentially measure them effectively, right.

So, there is a heat exchanger which is designed as part of this system. This is a Teflon tube and you can see it is coupled directly to IoT box which essentially aggregates all these sensors.

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What you also see is this little pipe here ok; slowly if you come we will pan the camera and then you will see that there is a pipe here. Can you see this pipe? This is interesting, right. As you have seen that the exhaust has one pipe and outside here is another pipe this is to measure the ambient air quality, right. Both of them are portable equipment designed in this project and we will have a look at them mostly from a box perspective and I will show you different components which go behind this system.

Now, recall that all our measurements are based on what we want our sensors the requirement from our sensors in terms of the sensitivity of measurement the range of measurement that we want to do. And this chart is well known to you already. You have seen this chart. This is an ambient air quality chart and there is also a chart for the exhaust air quality, right. So, remember these two charts and all sensors that have been chosen are essentially to cater to the requirements for this particular range, alright.

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So, now I will open the boot compartment shows up and let us now zoom in to the zoom in the camera to 2 boxes which are located here and now, let us try and trace what is actually happening. This ambient air quality monitoring tube is entering this top box. You can see that the exhaust is entering a down box; is entering a box which is located below the top box; now, its clear, right?

The down one is for exhaust air quality the top one is for ambient air quality. Both of them are powered using a battery here and there is a power bank which is powering the on board computer which is collecting data from both the sensors and we are using a simple mobile phone with internet connection for uploading data to the cloud. This is our basic setup you will see a set of cables here and essentially cascading between the two boxes and collecting data.

Now, what are the data items that we want to collect? Well, it goes back to what I mentioned to you we are getting NO 2, nitrogen dioxide, nitric oxide, ozone, ammonia, NH 3, hydrocarbons, particulate matter 2.5, particulate matter 10 all of them are measured from ambient and exhaust is nitrogen dioxide, nitric oxide, ozone should be nil there and ammonia hydrocarbons and particulate matter 2.5 and particulate matter 10. So, these are the main pollutants. What goes inside this box is the next question. What is inside this box?

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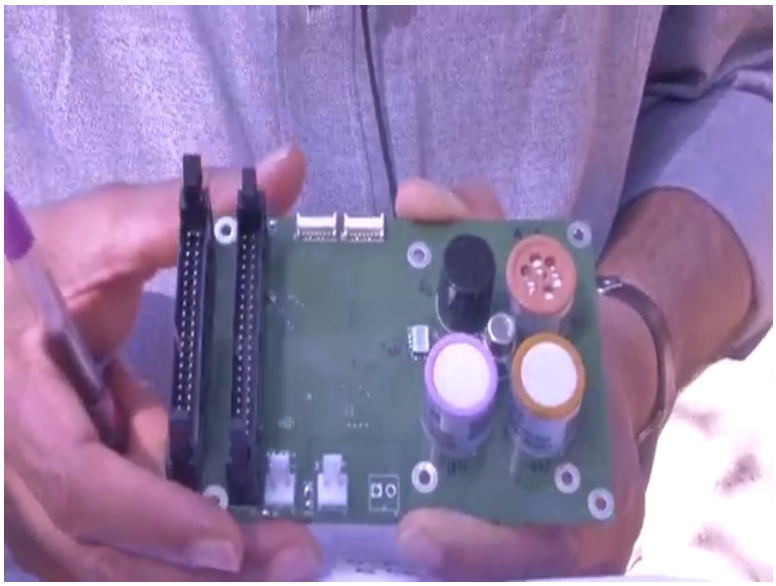

Well, what you see inside this box is essentially a bunch of sensors I mentioned to you about the different type of sensors that are there they are measuring different air pollutants. For example, the one that you see here is a semiconductor sensor we discussed this in great detail with respect to the MiCS 4514 from sensor tech which is measuring nitrogen dioxide.

This is measuring a hydrocarbons and this is measuring ozone and obviously, when you say ozone it is measurement of ambient ozone that is available. So, this is really an ambient a sensor board and there are other sensors which are measuring a nitrogen dioxide and so on and so forth.

This typically this essentially is a semiconductor sensor whereas, some of them are indeed electrochemical sensors. We have discussed the merits and demerits of each one of them we will not get into that detail. Let us close this and let us sit inside the car. What should you see now? Our good friend Paramesh is our driver here and he will sit in the driver seat of course and every time he presses the accelerator we expect that the exhaust will indicate high values of pollutants and in a way this project should influence how you should drive keeping pollution in mind and let us do that.

Now, as far as the demo plan is concerned as we drive along, we will take a left turn here go up and go straight and take a slight a elevation there where he has to press the accelerator to climb up and then we go out of the campus, go to a slightly polluted

region, typically a traffic signal and collect data from them, process that data and then let us discuss the outcome of this little trip that we did. On the way we might even stop to show you a typical value of a pollutant that comes from the exhaust.

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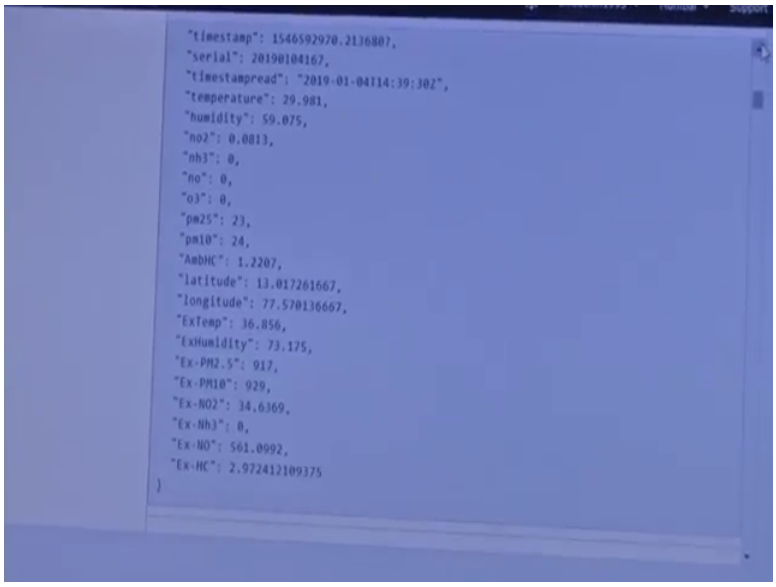

And we are on our way to cover a small area and you can see that the screen is reading off values as Sachin is holding on to a an equivalent of a dashboard which a driver would get in terms of the values of NO 2. And I will request Paramesh to accelerate a little bit on the height. So, that there is a certain rise in the pollutants coming from the exhaust here.

So, as you can see now the nitric oxide we want to measure in the range of 0 to 1000 ppm has now raised to a value of 400 as you can see on the screen it is 400 and its original value was around the 100. As you can see now we have moved some distance and the exhaust some of the parameters have increased you can see the particulate matter 2.5 has gone to 345; 10 is a 350, NO 2 has come down come to 16.75 and ammonia has to be nil. So, these are the values we have at the moment. As we go long this values will start increasing, decreasing as and when we drive and let us see them ones in a way.

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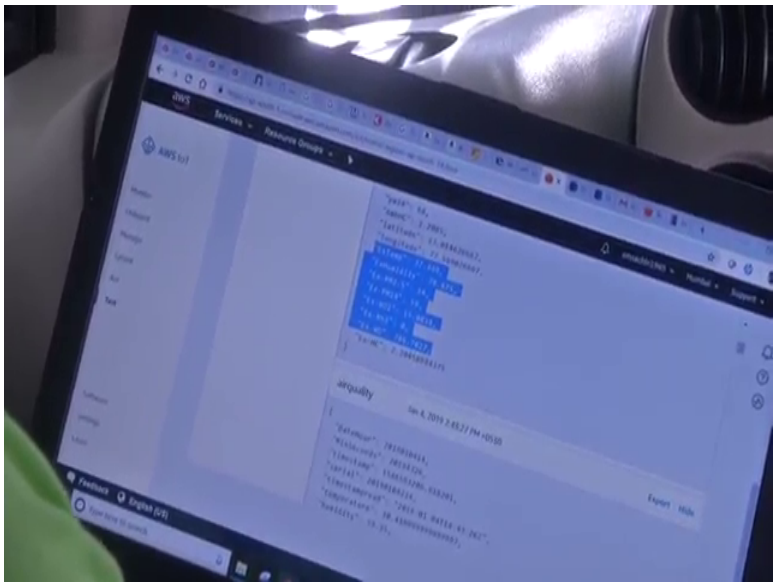

Let us now look at another snapshot of exhaust parameters. The temp the humidity has touched 78, exhaust particulate matter is at 54, PM 10 is at 56, NO 2 is 15 and nitric oxide is at 705, right it is at 705 ok. Let us move on ok.

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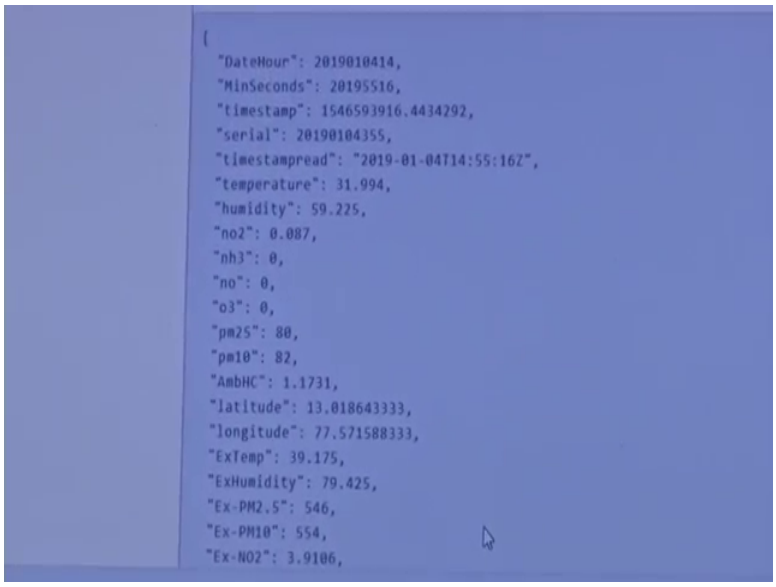

Now, you can see that at very high acceleration when the engine is rotating at very high speed you get a very high value of a particulate matter 2.5 as well as particulate matter 10. It has crossed absolutely dangerous levels and this clearly indicates that one should drive based on the values that are being indicated on the dashboard and its more I would

say air quality aware cars should come up which essentially will allow you to keep the environment safe. You can see now values have come down now because vehicle has set stand still and indeed it fallen down drastically ok.

So, now it is time for us to analyze the data that we obtained when we were driving in the car, right.

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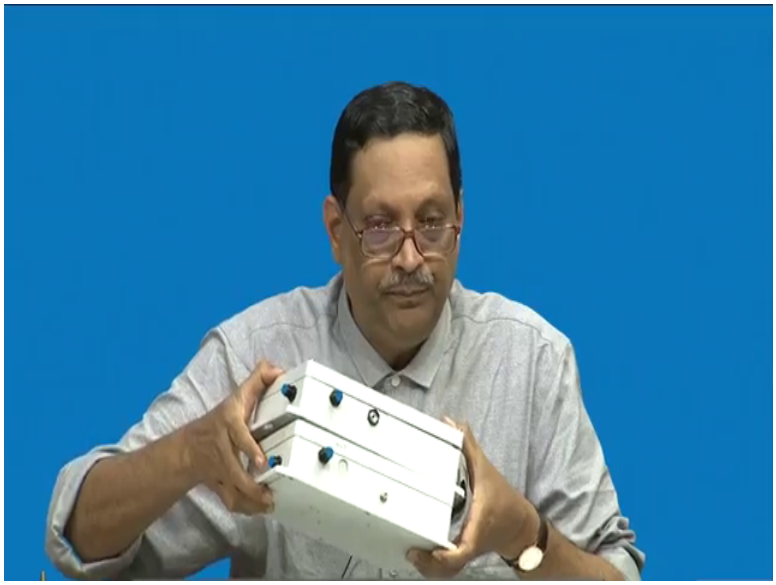

So, before you we go into the details of the graphs and other results this is what you had seen in the which were installed inside the car ok. So, in the boot space we had installed these two. As you can see one of them is for the purpose of ambient collecting ambient data the other one is with respect to the exhaust air quality, right of all the gases that we are gathering from the exhaust.

I mentioned to you one important point that it is not going to work, none of the sensors are going to work if you put the sensors in the corner of your house or just leave it inside the boot space of the car and somehow connect them to through a pipe, its not going to work. You have to extract the gas at a particular rate so that you maintain a certain flow inside, right. And I also mentioned to you that there are some sort of conventions about what should be the flow of such gases for proper measurement of you know any of these ppm, ppb levels of different gases and you have to ensure that it meets that requirement.

And how do you do that? So, you have to buy a pump, you have to install that pump and you have to study the data sheet and then perhaps it will tell you something about what is the flow rate. I mention to you that it is typically from 0.5 litres per minute to about 1 litre and some people even give you up to 2 litres. So, in our experiments we are you know sort of setting it up anywhere between 0.8 to 0.9 litres per minute and that is the flow at which the gases are entering these boxes. How do you measure that?

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Well, you can buy simple flow metres like this is a device from Honeywell and it is so, you could have an input. So, I can show you this is sort of an input output device there is an input and an output and across this if you if you have some voltage that comes out and this voltage is proportional to the flow rate. There is a very simple equation which will allow you to get to the flow rate. This is from Honeywell, you could buy this and I install it and ensure that you are adhering to the required flow rate of these gases so that a proper measurement can be done. So, this is about the infrastructural setup.

Before we went on to do the live demonstration I had given you some numbers and I had mentioned to you about what should happen and so on and so forth and you can see that reality is not what we discuss in the class rooms.

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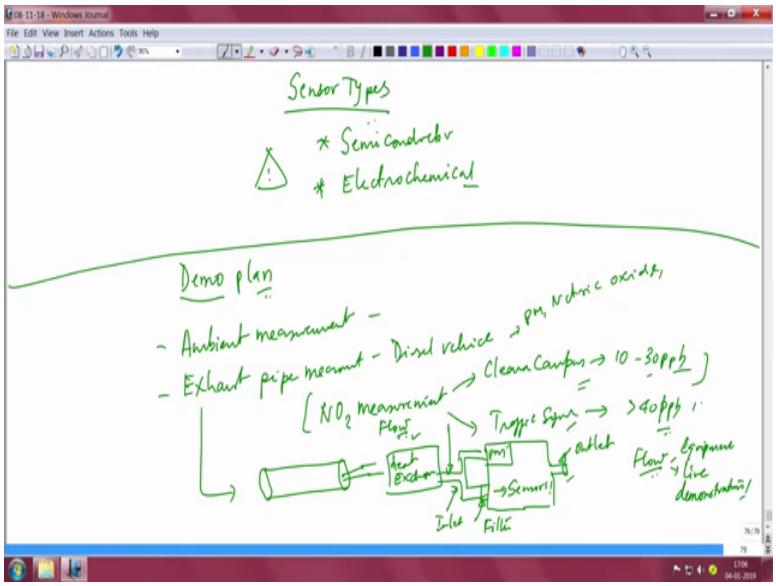

Look at this picture that I have drew to you. I mentioned to you that there is a exhaust pipe and then there is an heat exchanger that is up here and then there is a sort of a splitter which will take the gases directly inside PM which is particulate matter measurement. And then there is this other one which has all the other sensors which are inside this box. Of course, there is a filter, right and this filter is expected to remove those materials which can poison the sensors and bring down the life of the sensors.

And then there is an outlet, and we expect that NO 2 just I have taken only one example of NO 2. Clean campus we expect the values to be something reasonable and if you go towards a busy traffic signal with several vehicles at the traffic junction you expect slightly raised elevated levels of nitrogen dioxide. And you can also check for a particulate matter, you can check for nitric oxide, right and you can check for other pollutants which are harmful. So, you can check all of them.

Let us now turn our attention to those results which Abhishek and Sachin along with Harish have sort of compiled them together to give you a fair idea of how the results actually look like.

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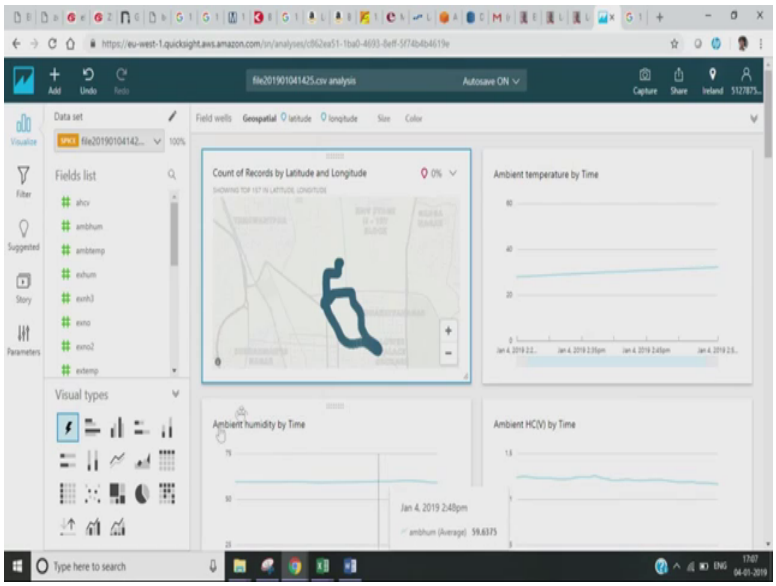

So, let us turn our attention to this graph. Let us look carefully. This is the starting point from where we started and then there is the lat long which obviously, is acquired by this box which I showed you and then we took a route like this we went like this we went like this we turned round we came back on another route and then we came back to our original destination. So, this was the small trip that we did.

And how did different pollutants play out? Well, let us understand that you can see that we started inside a campus and the ambient temperature was more or less you started with some 27 degrees and then it just built up to something like 32 degrees and I suppose this must be outside and that is spot it must have definitely shown a difference and definitely this inside campus will be lower and as you go along outside temperatures are much better because lot of concrete out there whereas, inside campus is a lot of tree cover.

So, let us rise is quite expected 2 to 3 degrees is what I would think we would get a difference, but this appears to be a lot more in this winter. So, there is a substantial drop in temperature.

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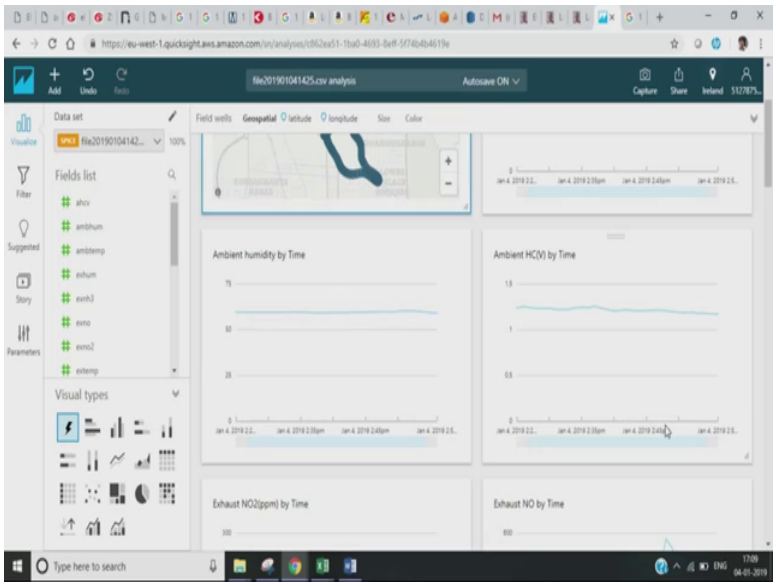

And humidity appears to be more or less the same. You can see that it starts of at some value which is close to 60 and sort of maintains the same all across. The hydrocarbon sensor can measure several hydrocarbons and therefore, its tough to say what is it you are looking for as far as hydrocarbon is concerned and therefore, we decided not to worry about it.

We just plot the voltage output from the hydrocarbon and therefore, you can see that its more or less you know at some value which has 1.2 volts to begin with and then it sort of also it is hovering around 1.6 volts with some peak somewhere here. So, it is hard to say at the moment what exactly this is coming out as far as hydrocarbon is concerned.

Note. that as far as hydrocarbon is concerned ambient air quality should measure somewhere in the range of your sensor should have sensitivity in the range of about 0 to 500 ppb and there is some. So, you have to convert this number into something equivalent of some ppb, but you can say more or less that the hydrocarbon ambient appears to be more or less a constant.

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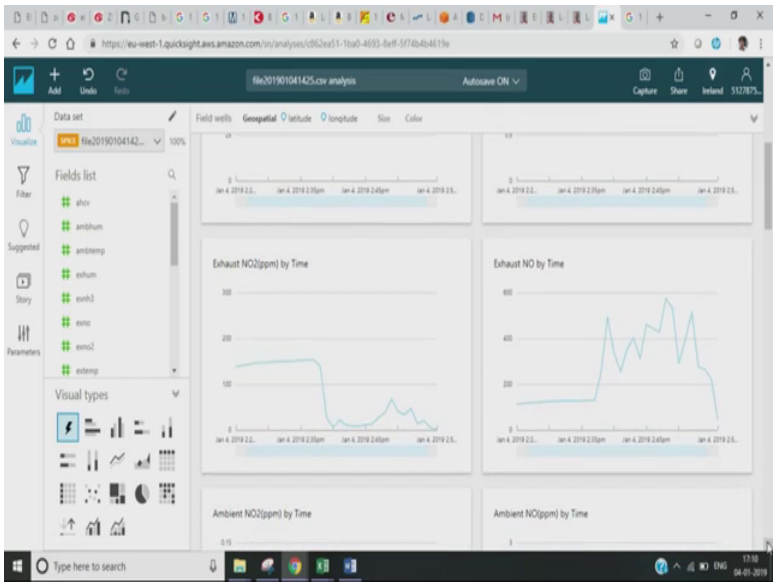

Let us move on to exhaust now. Exhaust nitric nitrogen dioxide we started off at this point and we move went through and then the vehicle took off and then we went some distance and suddenly there was a drop in the nitrogen dioxide and then again there was a raise of nitrogen dioxide as we went through our things and therefore, it is quite fluctuating.

Again, as I said I mentioned to you if it is exhaust the nitrogen dioxide is typically we need sensors in the range in a range which can measure up to about 600 ppm and this is in the range of roughly 140 or so picking up a little bit and then again falling to falling back to very low value and then again picking back to about 70 ppm or so. This is exactly what the exhaust pipe is providing us information on, it is interesting because the vehicle of interest is it is a Toyota Etios and it is you can see that you get a performance like this.

But, at the same time the nitric oxide definitely was low to begin with and as the vehicle started to move and then we started you know taking the root that I had shown you the nitric oxide starts to fluctuate quite a bit and there are points where the nitric oxide oxidizes to become nitrogen dioxide and those peaks perhaps are also because of the fact that there is a peak here.

For example a 249 PM shows a certain value here which is more or less coinciding with the 249, 248, 248 PM is a high value and that perhaps that little time was taken for the

purpose of oxidation and that conversion of nitric oxide into nitrogen dioxide must have happened in real time at out there and you can see there are other peaks which also seem to have come because nitric oxide seem to have oxidised quite successfully into nitrogen dioxide giving these other peaks as well. So, that is about nitric oxide over time.

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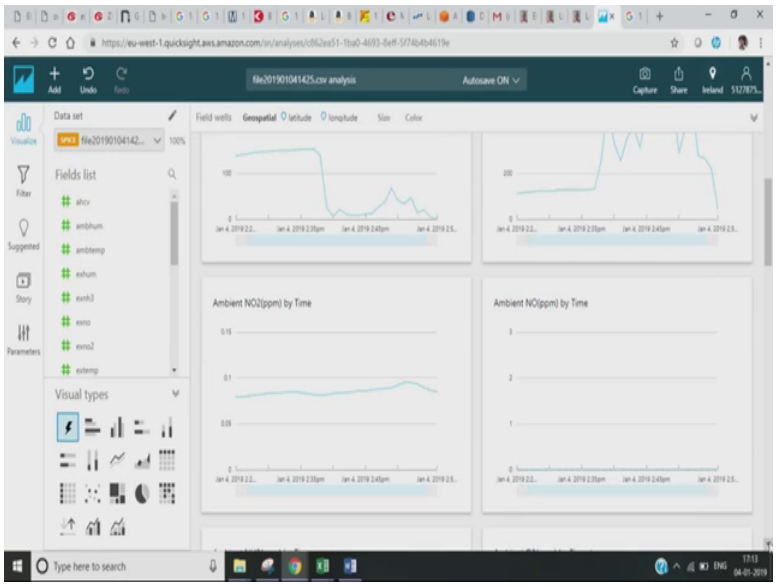

Now, let us look at ambient nitrogen dioxide by time. Ambient more or less ambient nitrogen dioxide should be safe for humans not to exceed about as I mentioned to you there is a very important World Health Organisation standard and there are numbers which you may want to look up there. But, anyway the measurement here is more or less constant and 0.1 ppm is 100 ppb. So, is roughly half of so, little over 50 ppb perhaps and therefore, it is going in the range of 50 ppb peaking sometimes close to 100 ppb and falling back.

So, ambient is quite high, its not in the recommended range of what it should be. Whereas, ambient nitric oxide should be in the 100 ppb and it appears not to be there at all, right. Definitely its only the nitrogen dioxide which appears to be significantly available in the ambient environment at the moment.

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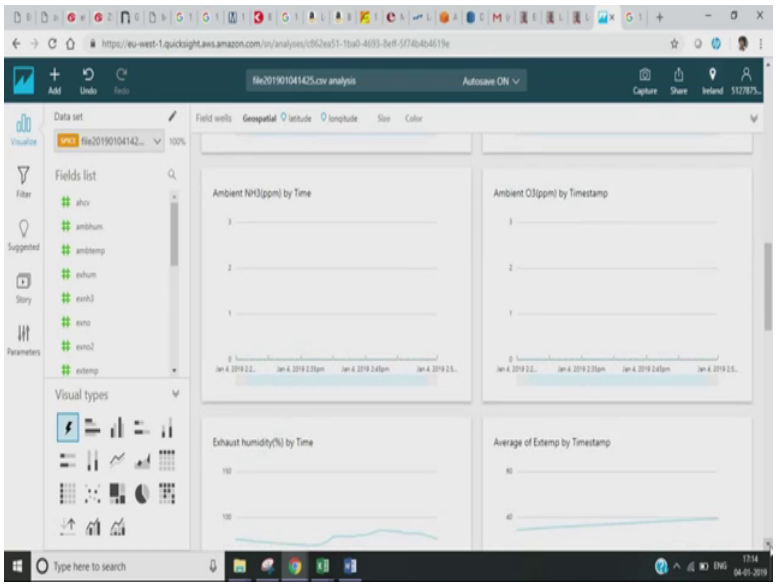

I am just juggling between exhaust and ambient just to give you a feel some sort of a comparison. Look at ammonia; ammonia in ambient is suppose to be also very low and your sensor that you require should measure anywhere quite linearly from the range of 0 to 200 ppb and you can see that is hardly any ammonia out there.

Similarly, ozone is also a value that should not be very high you need ozone sensors to be sensitive in the range of 0 to 100 ppb, but you realize that although it should be extremely low a sensor which has a good linearity support up to 100 ppb does not show anything at all. Therefore, one can conclude that ozone is very very minimal out there.

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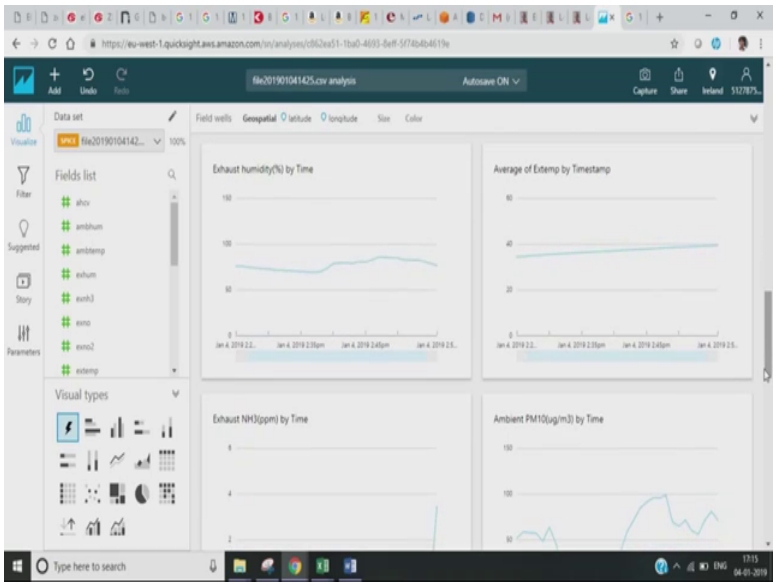

Let us look at exhaust. Exhaust humidity is fluctuating over time it began with a low number, but then when we started driving the humidity started to increase a little bit overtime and bit not significantly high you started with something in the range of 75 and it peaked perhaps to about 85 and then again sort of remain there. So, humidity is more or less I would say with this 10 percent raise seem to be out in a given range.

Same with the exhaust temperature here, this has to be obvious, right. You start the engine is cooled the gases are not because it is in standstill condition and then when you start driving there is a raise in temperature, this would have actually spiral to a very high value if our design did not incorporate the heat exchanger. This also shows that our heat exchanger is working well and we are able to ensure that the hot gases are you know cooled down within a very short time and also over a short range and almost equivalent to when the vehicle is stopped you are able to maintain.

So, you can see this value is roughly about 34 degrees and this peak is about 39 degree. So, about 5 degrees difference which is pretty good saying that mentioning that the heat exchanger design is quite good and it is able to remove heat from the system ok.

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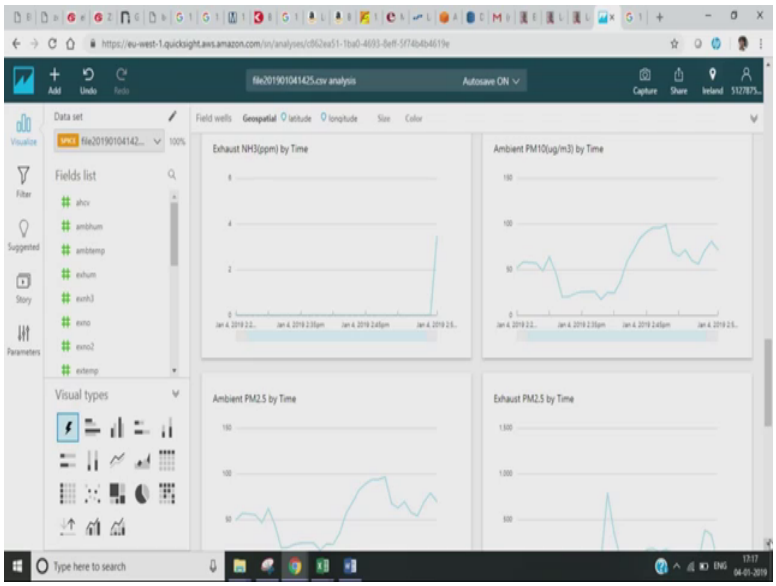

Go to exhaust NH 3, exhaust ammonia you should find significant numbers there, but your sensors have to be tuned for measuring a range anywhere between 0 and 600 ppm and you will see that exhaust ammonia is 0 all along and you get a small spike here. It is an out layer perhaps or some sort of a noise which is something that you may have to filter out. In any case it is not showing any high value it is a small number, but I am sure this must be some sort of a noise which seem to have come.

Now, let us look at ambient particulate matter. Ambient particulate matter, I mentioned to you many times if you look at PM 2.5 we will come to that, but PM 10 is also something that World Health Organisation comes out very strongly, that is the Indian standard which also gives you some numbers and let us now look at how good our sensor is in terms of its measurement.

This is being measured in micrograms per metre cube. PM 10 you typically want in the range anywhere between 100 and 150 micrograms per metre cube and you can see that it is starts off at 50 micrograms and is falls down. And then there is a nice raise in particulate matter and it will be interesting for you to understand why there is a raise in this particulate matter. I want you to think about it, I will provide you all the data that we have and it is important for you to analyze why this raise in particulate matter has actually happened.

Well, I know the answer, but I do not want you to I do not want to say this at the moment. So, I want you to figure out with all the files given to you, we will give you the GPS data, we will give you the time series, we will give you the NO 2 values that we got and I would expect that you work out and find out what could be the cause for the raise in particulate matter ambient ok.

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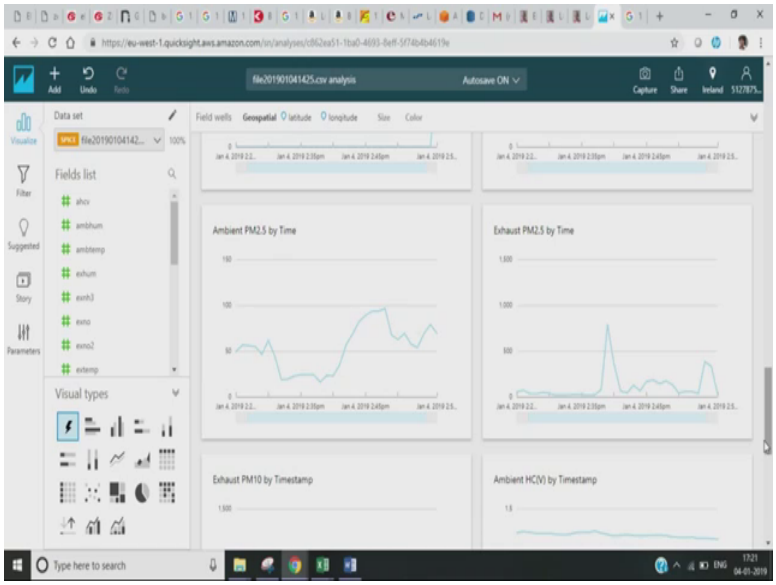

Now, then let us move on to a ambient particulate matter 2.5. You will see that ambient 2.5 World Health Organisation specifies 10 micrograms per metre cube, Indian standard says 40 microgram per metre cube and you are actually getting a lot more there you are getting 50 micrograms per metre cube to begin with and again there is a raise in the 2.5 microgram to 2.5 PM as well and it raises almost follows the same path as that of the PM 10 sensor. So, I want you to figure that out as well.

But, interestingly exhaust PM 2.5, what can be afforded as far as PM is concerned sensor range is should be up to about 30 milligrams per metre cube and you can see that exhaust does peak quite a bit at this stage and you again see that the value must be corresponding to 786 microgram per metre cube ok. This is expected because it is coming directly from exhaust, right and then there are peaks again.

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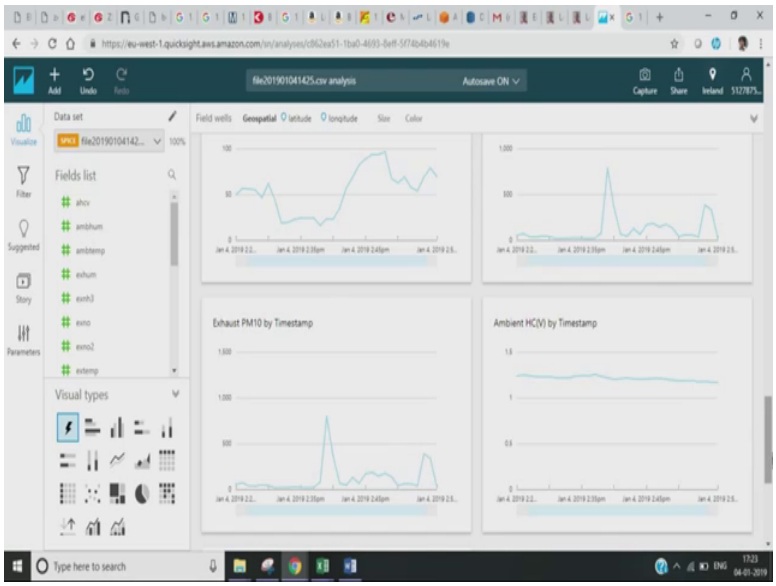

And also important for you to understand why this is peaking here. Again it is useful for you to analyse based on the data that is given to you. You know the time at which it has peaked, you know the location of the car when it at that time because of GPS, you have all the data available with you in order to understand why the particulate matter has actually peaked at that point.

Similarly, PM 10 as also peaked, so, that is out here exhaust PM 10. Ambient hydrocarbon we discussed this already. You can see that it is more or less some voltage level seems to have maintained some voltage level.

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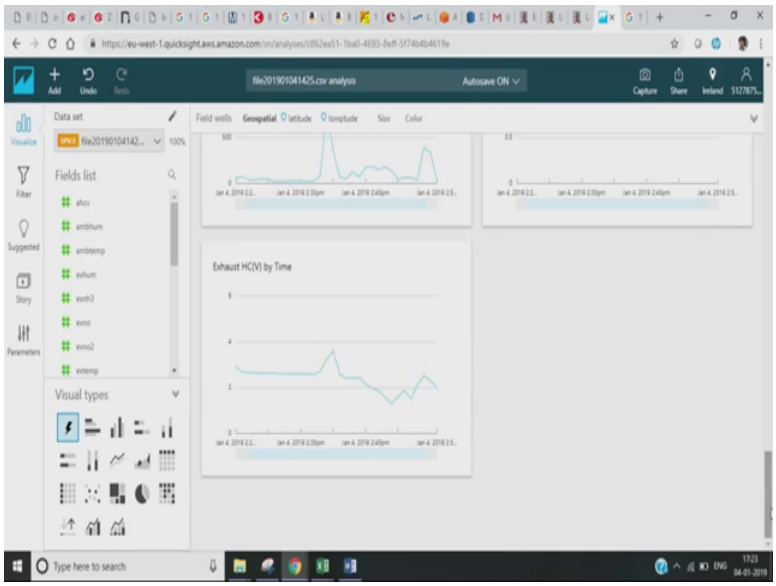

The exhaust hydrocarbon is expected to measurement range I would say should be less than about 2000 ppm and again there is some it is just a voltage value at the moment. So, I would not go into the detail of what this actually corresponds to in terms of ppm

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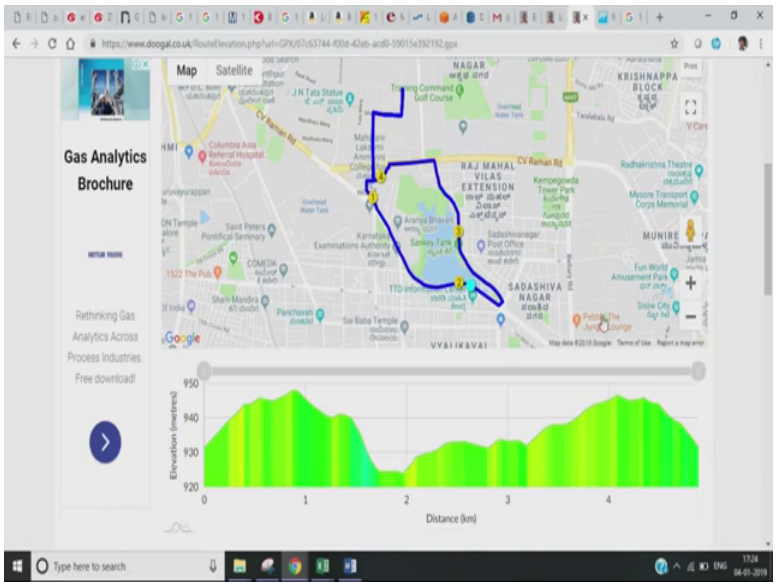

So, we have these results you can do lot of things once you have the data with you. What you see is the path that we took starting; went round like this; went to point number 2; went to point number 3; went back to 4 and then went back to the starting point. How did the elevation change?

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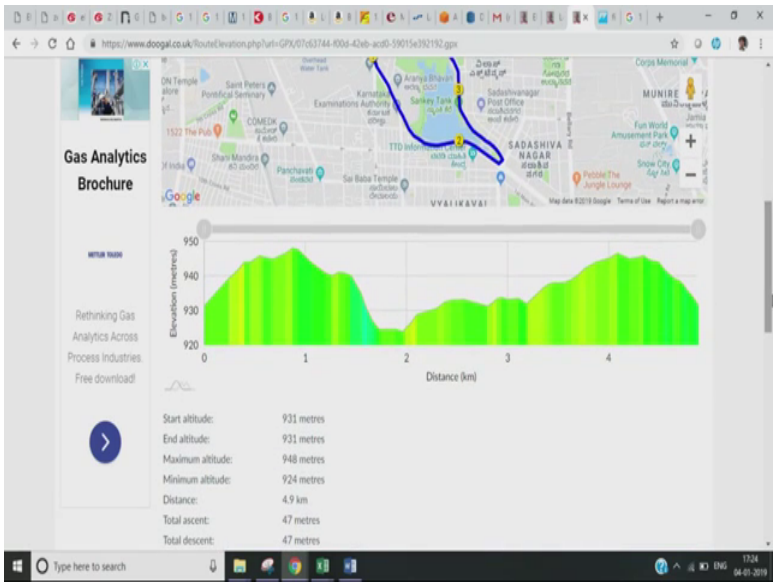

Well, that is interesting. You can see here starting point is 930 metres, this is where we started and this is where we stopped. So, both of them should correspond to the same point in the middle it went from 930 metres elevation to 945 about 15 metres and then we came back and then it took this path. So, that is what I am saying that you have actually the elevation data. Why with this elevation data what you could do can you find out what could have happened with the driver and how did he accelerate with if the this is a elevation data given to you will be of interest for you to interpret.

So, in summary you can see that we were able to take a route, design an IoT sensor system with the measurement of several parameters, fit it into a car, both measure the measure both the ambient air quality as well as exhaust air quality and come back, take the data, plot it and see where are the anomalies that are happening what kind of range these values are and so on is something that we have done. I must tell you that whatever I have shown you here with whatever ppb and ppm values the big disclaimer is I have not calibrated any of the sensor as of now.

So, whatever we have got from the vendor, we put them and we also got some standard calibrated sensors, we co-located standard calibrated sensors with these sensors, calibrated them and these are the numbers that we have got. So, take these I would say ppm, ppb values that you got from these vehicles with the some caution, purely representative data and not really actual ppm and ppb of a any vehicle.

So, this is the big disclaimers. The data is purely it is generated live, there is a trending that is happening, but you cannot take the value straight away because the sensors that were used are totally uncalibrated. However, there is some limited calibration which we have done with standard calibrated sensors. So, please use it only for learning and educational purpose, that is the big take away that I had to give you.

Thank you very much.