Design for Internet of Things
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Lecture – 03
Introduction to IOTTs-Examples

So, what we finally concluded is that change in magnetic field which we mentioned here can be demonstrated as change in temperature.

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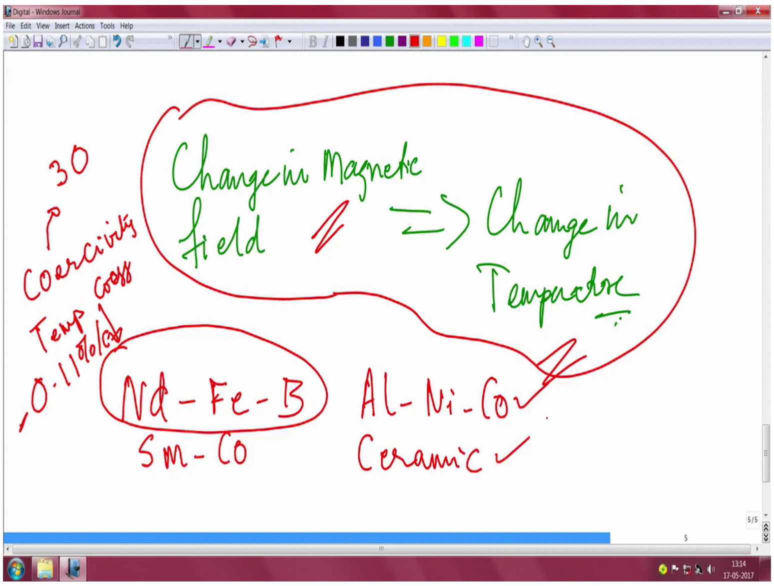

How do you measure this change in magnetic field? Let us go back to this nice setup that we have here and let us focus on this.

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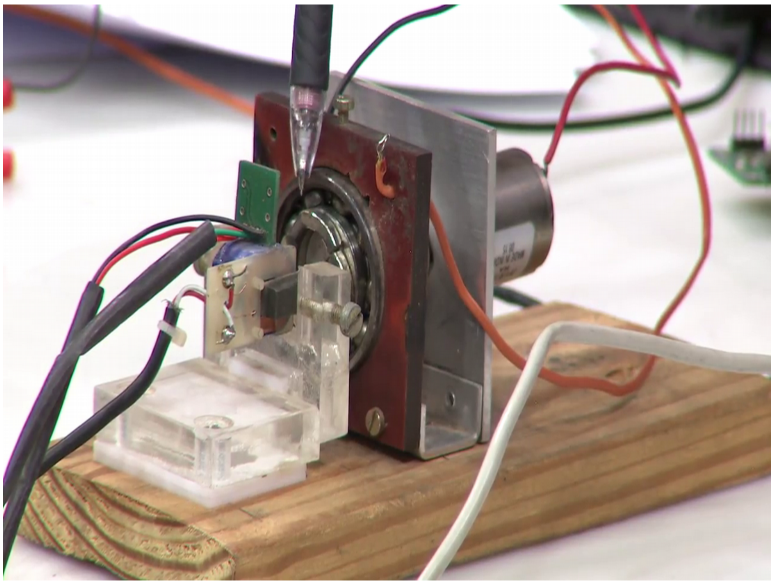

The change in magnetic field can actually be caught by these magnets which are mounted here, you can see this magnets this arcs which are mounted here and these arcs actually measure the magnetic field and the change in magnetic field; we are going to somehow co relate to the change in temperature. So, that is a nice way to do, if you have a change in magnetic field obviously, you need to look at magnets; different types of magnets are available. So, you may have to choose the right side of a type of magnets for such a measurement, sort of you know measurement conditioning that you will have to do; electronic conditioning that will have to be done, circuit that will be required in order to make this measurement very effective.

For that if you look carefully at the magnets which are available there are basically you know 3 types of magnets which one can actually put down. One type of magnet is the neodymium magnets, which is actually written as Nd-Fe-B, these are normally called neodymium magnets, then there are samarium cobalt S m cobalt magnets, then you have alnico Al Ni Co alnico magnets, and you also have ceramic magnets. So, you could choose any one of them. So, here is the problem you need to choose that type of magnet which essentially looks at very specific properties which are very nice properties; in order to meet this requirement of change in magnetic field which will essentially correspond to change in temperature, because you are really looking at bearing temperature.

For that you have to look at what is very important is the coercivity associated with this magnet you can actually call it coercivity, you should look at this property Co er c v t is an important thing and also the temperature coefficient because that is of great interest when you are trying to measure the temperature coefficient I suppose is a single word. So, I will just in anyway abbreviate it, but I should not further reduce it. So, temperature coefficient this is typically this has this neodymium magnet essentially has the highest coercivity, some number and I am go to write down that number which is 30 and there is a unit of course, I let you figure out what is that unit of coercivity, and it also has temperature coefficient which is 0.11 percent per degree Celsius and with a minus sign I also want you to figure out why this minus sign is there right? It is quite obvious, but you will have to perhaps think a little bit to see why this is really written as minus 0.11 percent per degree Celsius fantastic.

So, if you now come back and say I have to measure the bearing temperature which is here this is the ball bearing this is a magnet I have to choose, you can see already when you talk about it designs for IOTs you are actually talking of choices all the time design essentially means you cannot be just talking about one option one particular way by which you are biased to a particular design, the design has to be very optimal the design has to choose rather the design has to fit the requirement that you are looking at. Again hear you see the design coming out, you wanted to use magnets for the purposes of measurement of temperature change in temperature; for that we said four different magnets neodymium, samarium cobalt, S m C o then you said alnico and then ceramic.

You have to choose one of them again and then that means, essentially design means is just not one aspect, but you have to keep looking at design alternatives and choose the best possible alternative. Now it might turn out that you may say why is this method the most appropriate way to measure the temperature of the ball bearing why are we choosing this method at all why do not we choose a let us say some temperature sensor methods some in non invasive temperature method systems right. Now the reason why we do not want to do that let us go back to the setup again, the reason you do not want to do that is because most often these bearings are deeply embedded inside automotives any run any machinery which rotating machinery which essentially you are trying to transfer power or you are trying to put in any rotating systems you have these bearings which essentially will allow which are trying to monitor trying to do a monitor them for their condition.

These are all deeply embedded these are enclosed in certain systems. So, any non invasive method of measurement is only going to measure the enclosure of the casing, it is not going to actually measure the bearing directly. Remember you look at this magnets they are paced placed on the inner race of the bearing, and you have measurement systems electronic measurement systems which are directly reading of the temperature and actually measure measuring the magnetic field and how do you capture that that comes from this board. This is a hall sensor and you can see that this electronic essentially is measuring the magnetic field the change in magnetic field you start reading the initial magnetic field, and if the bearing is doing bad there is a change in the magnetic field which is directly captured by this hall sensor electronics; and all of this electronic is now coupled to the required communication units and so on and so forth.

Now, the interesting part is this particular system essentially will focus on how do you actually put together all of this well.

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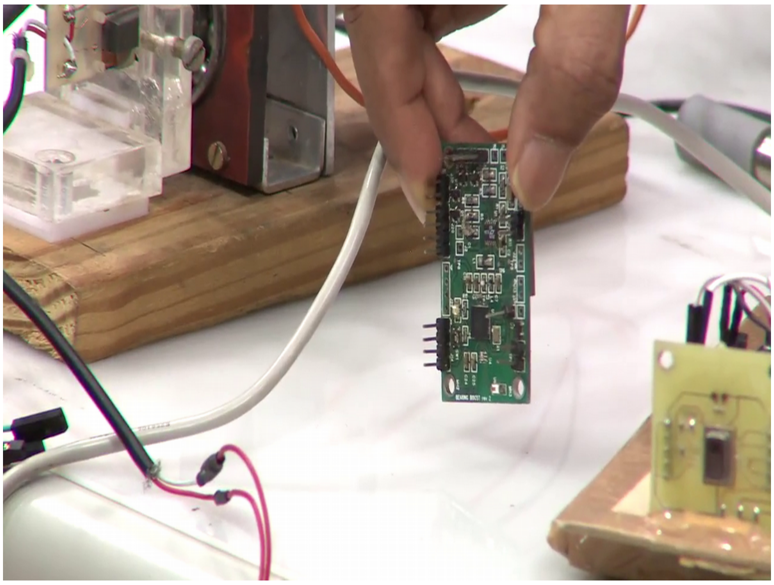

We mentioned about a board which was like this, you can see that this is the p c b that we developed in the lab essentially has interfaces for connecting these wires directly to this system and has a sort of an energy storage device which is here this is a super capacitor or an ultra capacitor as they are called which essentially stores energy for measurement of this bearing temperature.

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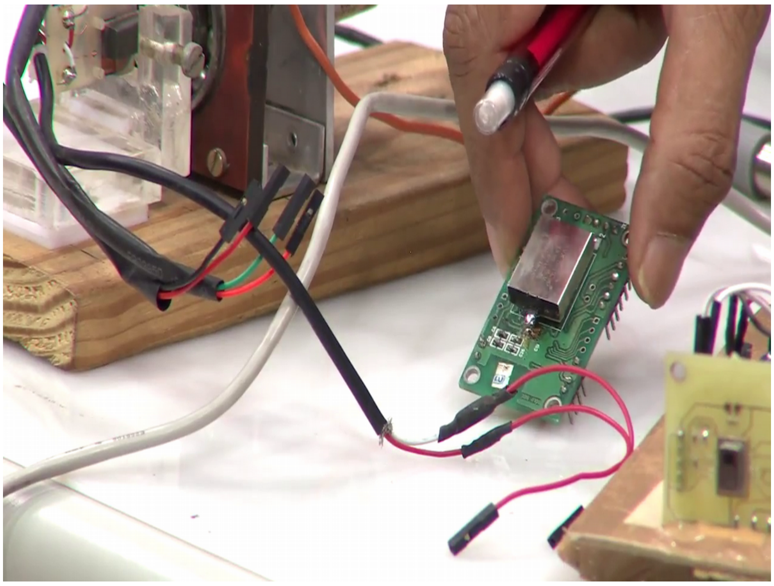

Behind these are all the required power management circuits and the communication module. Let us look at a little more detail at this communication module, you will see that there is this little system here which perhaps you may want to I put it this way no maybe this way a little bit I will put it this way and show you the ok.

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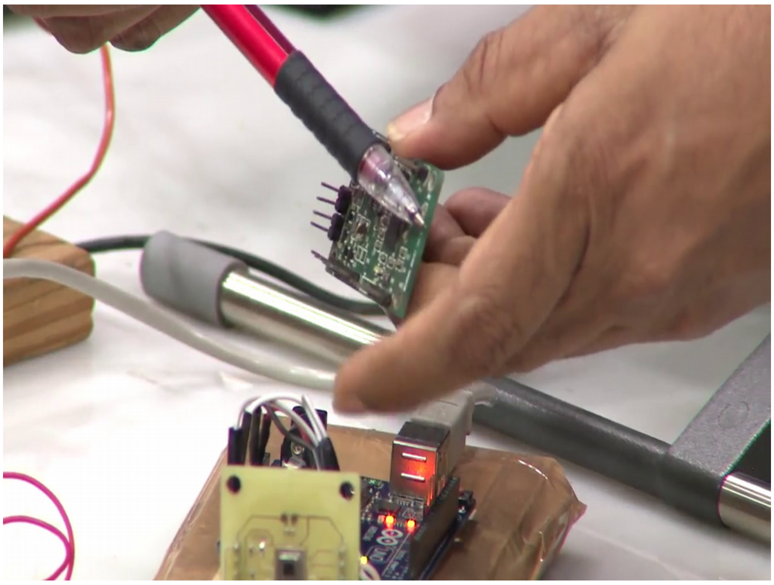

So, you see this little white portion here this is this white portion here essentially is the chip antenna of a Bluetooth low energy module, which is integrated into this SOC. This SOC is essentially a system on chip as it is called is from the; from a company called Nordic semiconductor.

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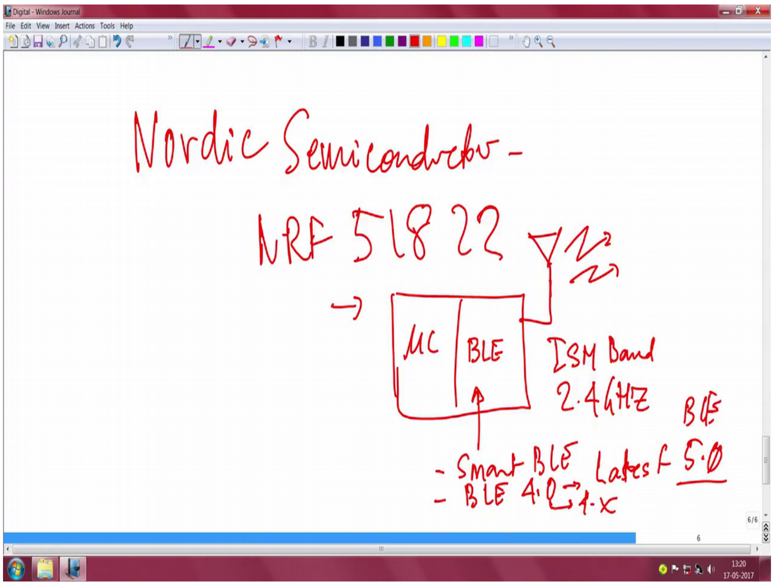

So, I will write down Nordic semiconductor is the name of the company from where we bought this chip, this chip is called NRF 51822. A very popular microcontroller we will not get into the detail of this microcontroller at this stage, but just to tell you that this system has a microcontroller and also has a Bluetooth low energy radio, which is integrated into the system. As you know Bluetooth low energy uses ISM band, ISM band frequency of 2.4 gigahertz works in the range of 2.4 gigahertz, and is also called Smart Bluetooth, sometimes they call it as they it is also Smart Bluetooth and some people and in fact, it is actually the BLE 4.0 system, and this has advanced now and now the latest indeed is moved over to the latest. So, let me write it the latest indeed has now moved over to latest, latest is actually the 5.0 BLE; we will get into this detail a bit later, but there were different versions here there was a 4.0 and then I would say 4.X essentially some improvements to the basic 4.0 indeed have happened over the years.

But never mind the point I was trying to drive at is that this temperature that we were trying to monitor here on this system here this temperature here was read by this samarium sorry the neodymium magnets which we explained which we showed in the previous chart which we said is neodymium magnet, these by the neodymium magnets which were connected to this bearing, and it was reading the change in the magnetic field using hall sensors and after that all of that being interfaced to this nice little SOC. So, you can see this is a nice IOT system and a fantastic way of measuring the temperature condition monitoring of a ball bearing, and I pointed you to the paper which actually inspired us to build this complete system. We will look at some results of this board, but before I close I want to tell you what this board actually has this board is essentially I will draw a picture of this board. So, let us go back and draw what all does this board actually have.

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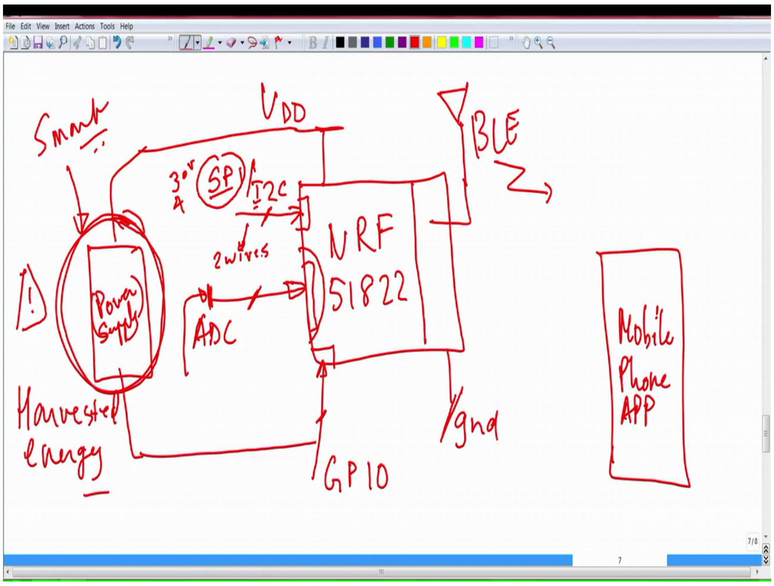

This board in the heart of it actually has this NRF 51822 grid eye and of course, we mentioned that this 51822 indeed has a Bluetooth low energy module for wireless communication; to typically let us say a mobile phone app, mobile phone app or perhaps the dashboard of the driver because let us resume that this is a ball bearing that is part of an automobile and the automobile bearing temperature is being measured and being displayed on the dashboard of the automobile driver or it is also possible that this ball bearing is part of a operator in a workshop, in a factory setup where there are lathes for instance or a milling machine on lathe system which is essentially which also has a lot of these ball bearings for rotating anywhere where there is a rotating system with a motor connected, you will need these ball bearing. There are different sizes let us not get into that detail, but any rotating machinery will require this ball bearing and this ball bearing temperature is now being monitored by let us say an operator, who is interested in knowing how the equipment is actually functioning.

So, it could be just that he has a mobile phone in his hand, and any critical parameters actually displayed directly on his mobile phone. Look at this IOT system there is equipment which has this system, and then you are trying to monitor several parameters critical parameters of the equipment itself the condition monitoring of this equipment itself. What is the novelty now of this board we mentioned about this board right this board has certain novelty, and why did we why is this board very important and what is it trying to do both back as well as in the front portion.

Let it go back and put on what are the most important things. This NRF obviously, has to be fed power right some power which essentially means that it needs a VDD and a ground. So, let us call this VDD and ground; the good thing is this NRF which essentially is capturing data from the hall sensor through some of its interfaces, if it is an analogue interface it will be through an analogue to digital converter interface. If it is though a let us say a binary status it will be through a general purpose input output GPIO or if it is through any of the digital bus interfaces, it can either be through what are known as SPI or I2C interfaces these are digital buses. This is an ADC analogue interface this could be a still simple binary status of 1 or a 0 which could be coming through a GPIO. So, let me move this so that we draw our picture better this is ground and this is the GPIO, this is an ADC and this is SPIO or I2O. So, this is ADC actually it is written here ADC and I just wanted to demonstrate. So, I will improve this picture.

So, this is ADC this SPIO this is GPIO fantastic. What is the novelty of that board? Boards novelty indeed is powering this board; this power board power supply or power VDD for this board is actually being harvested from the system itself.

So, I will show this. So, here this block is the most critical block pay all your attention here and this is harvested energy. How is it harvesting how do we you know satisfy our curiosity let us go back and look at this board, and let us actually look back at this system; what actually we have done to this system is, if you look carefully there are these magnets right which are connected to the which are in close contact with the inner race of the bearing that is what we said last time if you look carefully, this is the hall sensor electronics this one this hall sensor electronic essentially has these this there is actually a coil here which is connected maybe I will rotate and show you in a different perspective.

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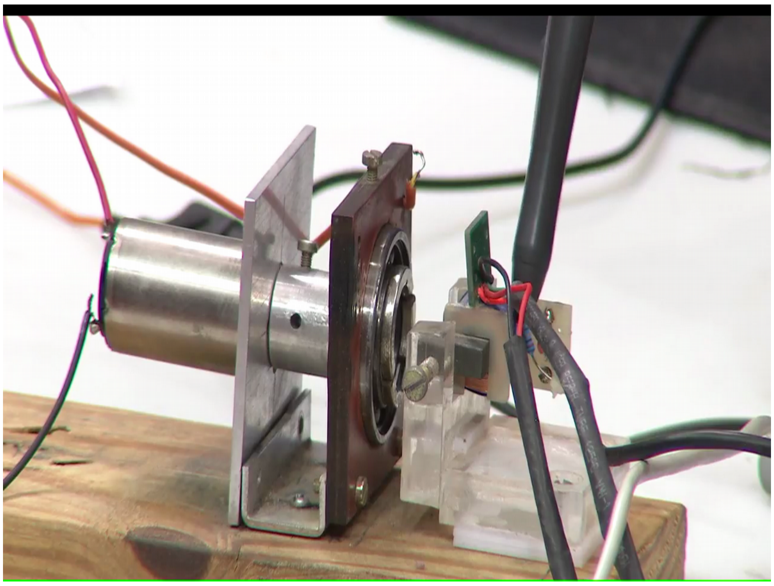

This you see is a coil, this is a coil this is essentially a coil and it is actually inducing certain electricity certain amount of energy because of these neodymium magnets which are attached for the purposes of sensing the temperature of the bearings.

So, what are you doing? You are doing a peculiar thing here in the sense that you are not only measuring the temperature of the ball bearing, you are also using theses neodymium magnets for inducing a certain amount of energy voltage basically and a certain amount of power from this coil which is connected here, this is the coil you can see this blue one bluish colour here this is a coil essentially. So, and this coil is essentially giving you a certain amount of power out, every time this bearing rotates it induces a certain amount of voltage here. So, there is a certain amount of power drawn, you condition all that power using this PCB on which there are diodes if it is giving you an AC output.

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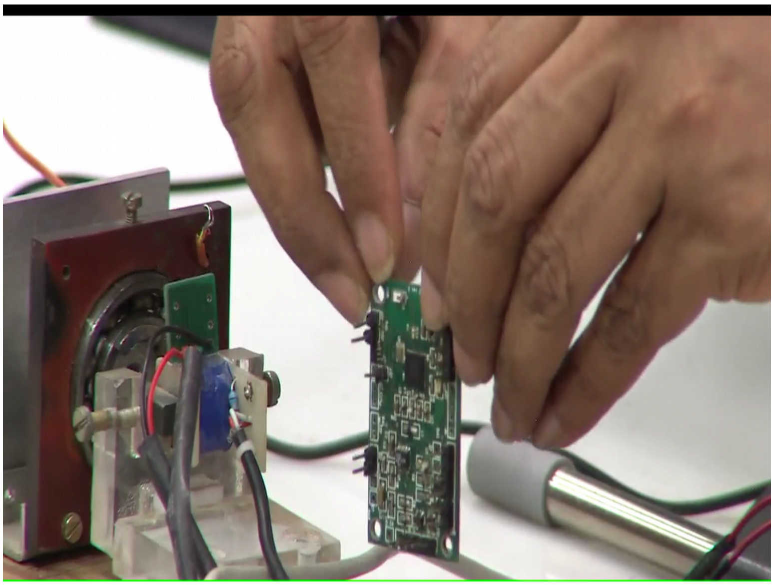

Rectify the supply and store that energy on this capacitor here this is a super capacitor, and use this energy for the purposes of powering the hall sensor for temperature measurement.

So, you can see you are actually bootstrapping the whole thing by rot by initially rotating anyway the system rotates and certain amount of energy is induced, certain amount of voltage induced by this coil here, and that powers this board here you do very clever power management put a very clever power management circuit which I have shown here in this block, put a very very clever power. So, I call this smart; put a very smart power management block here and you supply power back to this NRF, for the purposes of sensing; sensing could be either through analogue to digital conversion ADC ports or SPI I2C which is a digital sensor.

Indeed in this specific case we are actually using the ADC. So, actually the hall sensor output is connected directly to this ADC here, and this is actually measuring the ADC samples which are actually indicating the temperature of the ball bearing fantastic. So, this is a big summary of a nice IOT system that you can imagine where you will have to look at ways of measuring a certain parameter, where you will have to look at design alternatives every time when you say design for IOT, you say look at alternatives in there is no one particular design which is best, you have to look at that is what you will learn all through your engineering that you will optimise one design for that particular application, but they can be many alternatives and this is one such alternative measurement.

Now, let us look at all this is fine is this the only way to measure the whole thing about bearing temperature, why am I not using other methods of measurement. Let us look at let us say a most popular way by which you do not want to be in contact with the bearing, but you want to measure the temperature of the bearing could be using IR temperature sensors non invasive IR temperature sensor. So, let us shift our focus to another type of sensor which is here which is essentially a sensor which is from a company called Panasonic.

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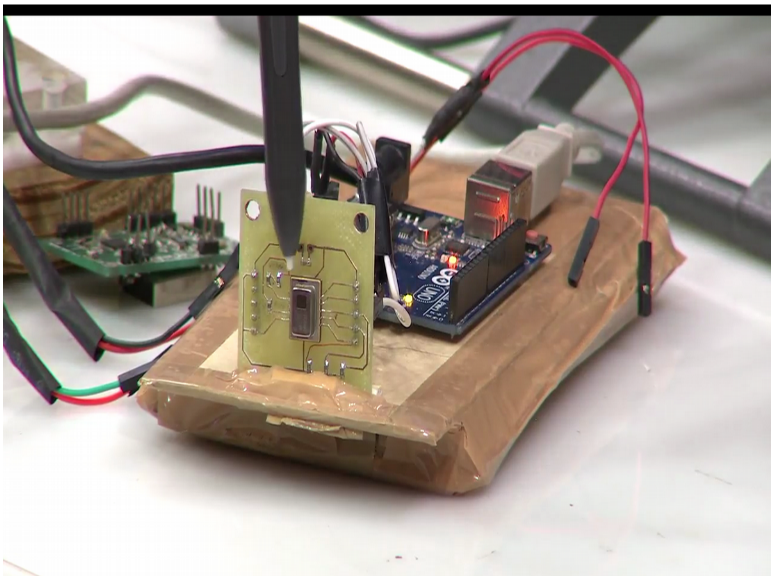

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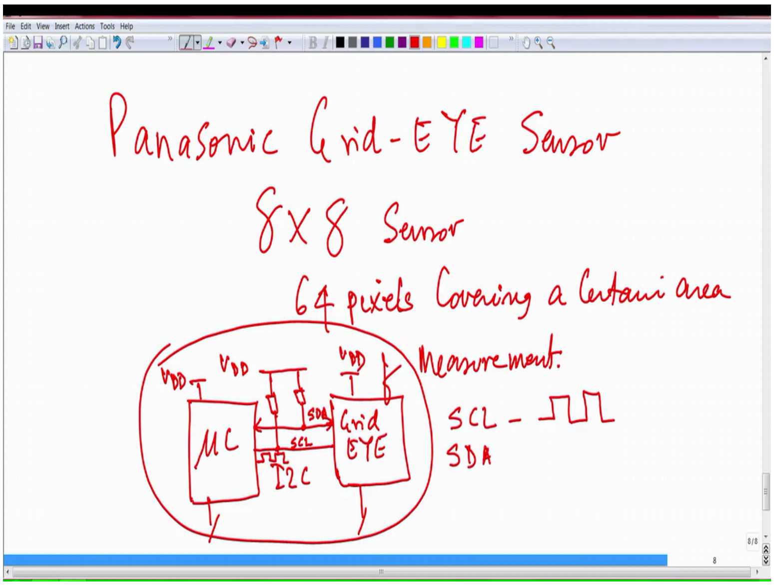

This is a Panasonic grid EYE; EYE sensor, this sensor is an 8 cross 8 sensor; that means, there are 64 pixels covering a certain range or I would say certain area, certain area of temperature measurement area of measurement. So, how is this grid eye sensor interfaced to the whole to the microcontroller? Again it is the standard way, you have a microcontroller block I mentioned to you previously about digital communication block in this picture you can be talking about the digital communication module which could be either through SPI or through I2C this is nothing, but inter IC communication I2C is actually called inter I C communication SPI is serial peripheral interface this essentially uses 3 or 4 wires physically between the systems on which you want to do a communication and I2C essentially uses 2 wires.

So this microcontroller is essentially communicating to this grid eye over I2C interface, which means this you, can now rub off this line and nicely replace it with 2 lines here, and this is the grid eye sensor. Now I will draw sorry; this certain area of measurements. So, I will just remove this here to these will have to be connected to essentially I can write with a single line here you some VDD here of course, this is VDD and this is ground this also needs power. So, VDD and you need around here. These 2 lines essentially are called there are names associated with this I2C one is called SCL and SDA obviously, SCL indicates serial clock.

So, let us call this SCL and this is SDA these are 2 pull up resistors to VDD, we can look at typical values of these 2 resistors as we go along, but for the moment assume that these to pull up resistors are required and this SCL essentially is the clock and SDA is the data which flows between the grid eye to the microcontroller or microcontroller giving a command to the grid eye sensor over a clock so as simple as that.

This is the essential interface going back to this setup let us see how this whole thing that I have shown here, this whole thing how is this realised in actual practice let us look at this hardware. This hardware you can see has this Panasonic sensor here this is the grid eye sensor and if you look what all we have done with this, this is a standard Arduino board right, this is a standard Arduino board this is the microcontroller board that we have been talking about. So, its interface between the 2 of them and what do you see if you develop this I2C driver and focus it on the any surface that you want to measure, you will see 64 pixel elements which I am showing here.

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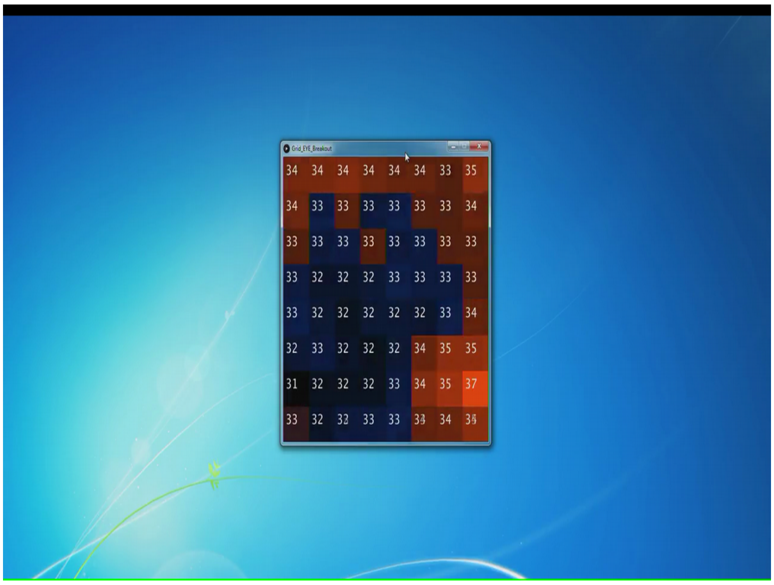

These 64 grid eye pixel elements that you see are essentially indicating the temperature, if I change the direction of the grid eye sensor this will also change. You can see let us first focus this grid eye sensor on one particular in one particular direction. So, let us now refocus back on this grid eye sensor. So, let me put the grid eye sensor like this, now let us see the snapshot here look at the snapshot, now let us look back at the grid eye sensor and turn it around like this.

Now let us look back there you can see. So, you can see each of this you can count them that there are 64 pixel elements, there are nice colours indicating the temperature which are the colours are actually relative; you can see that the temperature of each pixel element is changing in a few areas for example, the first pixel element is changing by 1 degree 35 34 and so on, the second pixel element is actually changing to a 36 and so essentially this is giving you an array of temperature values over which it is actually measuring the temperature.

Now, you may ask what is the specification of this kind of grid eye sensor for that, let us put down the most important specifications most important specifications that you may have to look at.

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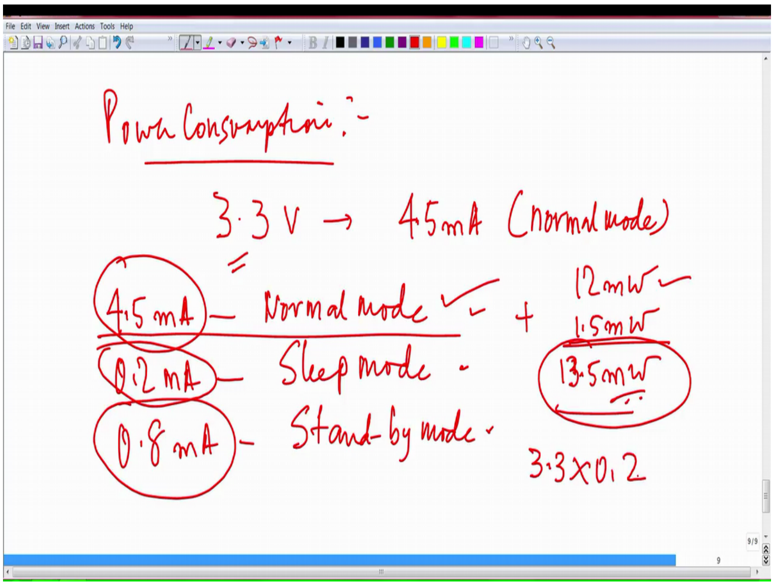

First thing you would be worried about is what is the power consumption of such a sensor; well what we have done is we have operated this at 3.3 volts and it takes a current typical current consumption of this sensor is in let us say 4 is actually 4.5 milliamps under normal mode. There are other modes that the sensor supports which may not be of much use at the moment, well you will have to do power management by looking at this particular thing.

So, let me for completeness let me just put down these 3 grid eye specification put these 3 numbers, 4.5 milliamperes under normal mode, 0.2 milliampere when it is under sleep mode, it is under a sleep mode and 0.8 milliamperes in what is known as a standby mode. We will just consider this particular normal mode while it is a why is why are these 2 more other 2 modes why are these modes important? Essentially when you talk about IOT design for IOTs and your putting your basically you know sensing physical environments and your driving them out of batteries, you have to really worry about how long do these batteries last, what is the cost of replacement of these batteries there is a cost associated.

So, unless you maximize the amount of time these device are actually monitoring or diploid for a particular purpose unless you maximize the lifetime, it is going to incur a huge the IOT deployment itself will incur a huge cost, which may not be worth sometimes when you really when you look at very large, scale because people are actually talking about this is there are studies which talk about billions of devices by the year 20 grid eye billion some reports say 20 billion, some reports say 50 billion. So, all that indicates that there will be huge number of devices and each of these devices are powered using batteries. Well that is a question right which we will try and answer in this course and look at is battery the only way can you do something interesting which we already explained now that, you can actually harvest energy from the environment itself. So, we are just opened and said this is a good possibility you can harvest energy opportunistically from the system itself, but let us look at the whole gamut of energy harvesting in a much more structured as we go along.

But before we go into that detail you must look at these parameters of 4.5 milliampere normal mode, sleep mode and standby mode only because you want to maximize the power consumption of this you want to minimise sorry you want to minimise the power consumption of the complete IOT system including the sensor right. So, we are operating at 3 at 4.5 volts, and we are consuming a 4.5 milliampere if you do a simple multiplication this will give you 12 milliwatts, plus 1.5 milliwatts this is 4 into 3 is 12 milliwatts, 5 into 3 is 1.5 milliwattts I add both of it will give me 13.5 miliwatts. So, it is not bad it is ok but it is still quite a bit of power. 13.5 milliwatt of power if you keep it in on all the time therefore, you may want to look at options of shifting it to a standby mode and also sleep mode; sleep mode is quite nice because if you are not using it is not going to consume much. I would like to stop here.