**Introduction to Embedded System Design**
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**Lecture 01**
**Introduction**

Hello, welcome to the first lecture of this online course on Introduction to Embedded System Design. I am Dhananjay Gadre, I teach at the Electronics and Communication Engineering division of Netaji Subhas University of Technology in New Delhi. During this course I will be joined by Doctor Badri Subudhi who is a faculty at the electrical engineering department of IIT, Jammu.

Before we start with this course I would like to go through the course objectives so that you are aware as to what you are going to learn out of this course. What we are going to do is to learn about Embedded System Design and the applications of these embedded systems. We will teach you how embedded systems can be visualized in a 6-box model that we have developed overtime.

These 6 boxes include the input box which has human inputs and environmental inputs. The output box which has outputs for humans as well as for actuators, the power supply block which powers the entire embedded system. Communication block which allows the embedded system to communicate with the outside world if needed.

A storage block which allows the embedded system to store user data or information and the most important of it all the embedded commuter block. And all these blocks will also be glued together with the help of what we call as electronic glue then we will do details of how the embedded computer is implemented. There are many ways of implanting the embedded computer. One of the popular methods is using a microcontroller. Microcontrollers are nothing but it is like a complete computer on a single chip.

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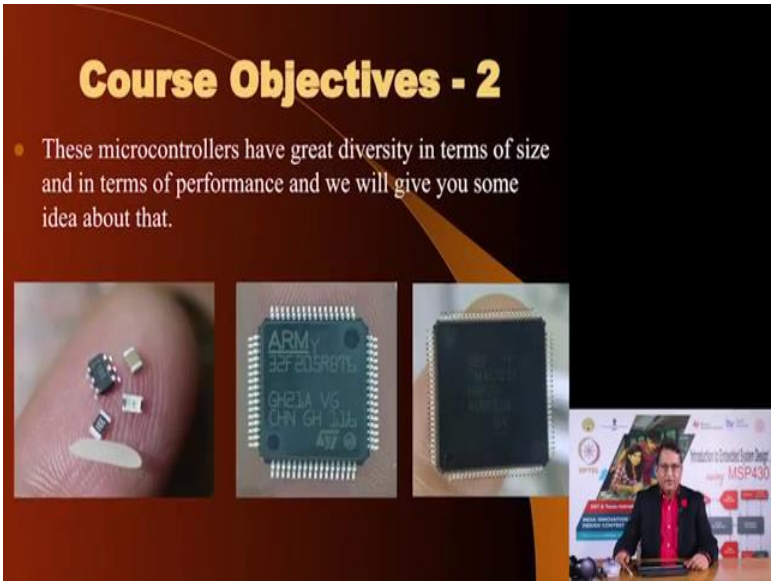


These microcontrollers have great diversity in terms of size and in terms of capabilities that is their performance. In this slide you can see 3 examples of microcontrollers. One which is smaller than a grain of rice and the right most example is something which is about 1 square by 1 square inch in size.

What we will also do is we will for this embedded computer implemented through a microcontroller we will take a real example and we will cover Texas instruments MSP-430. Texas instruments is supporting this course as I mentioned in the introductory lecture, they are giving a kit for MSP-430 microcontroller that was designed in my lab.

We will teach you about the MSP-430 architecture, the programming and interfacing to the outside world. We will teach you embedded C programming and how to write debug and download the program that you write on your desktop computer after compilation, how to download the object code or the binary code that it is called into the memory of the microcontroller.

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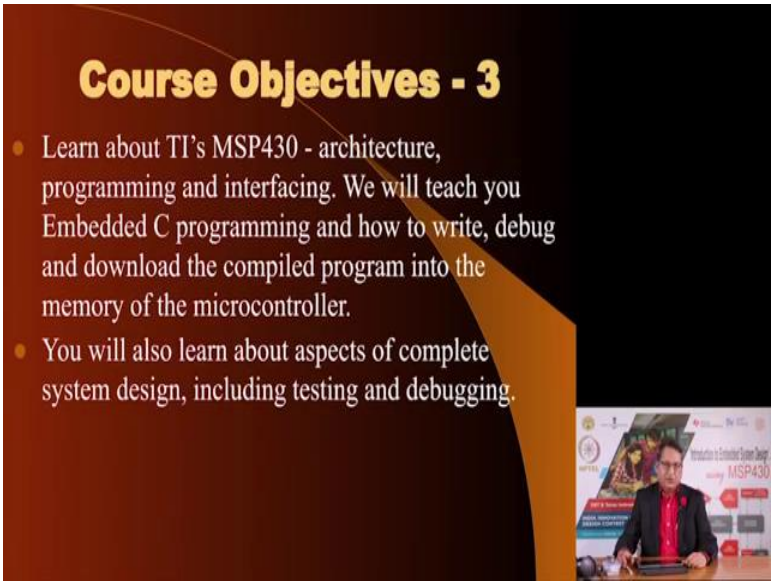


We will also learn about various aspects of system design including testing and debugging and at the end of this course you can expect to be able to design, visualize design and implement an embedded system from scratch to finish. However, these are the objectives, specific to this course, I have certain objectives beyond this course and my objective is to do things so that you as a participant, you as a student of electronics fall in love with practical electronics.

I would love to do in this course something that would enthuse you to build circuits and systems starting from simple circuits to complex circuits and eventually to be able to visualize and built complete systems and products so as to make India self-reliant. After we have covered the course objectives let us go through the prerequisites which we expect you to know.

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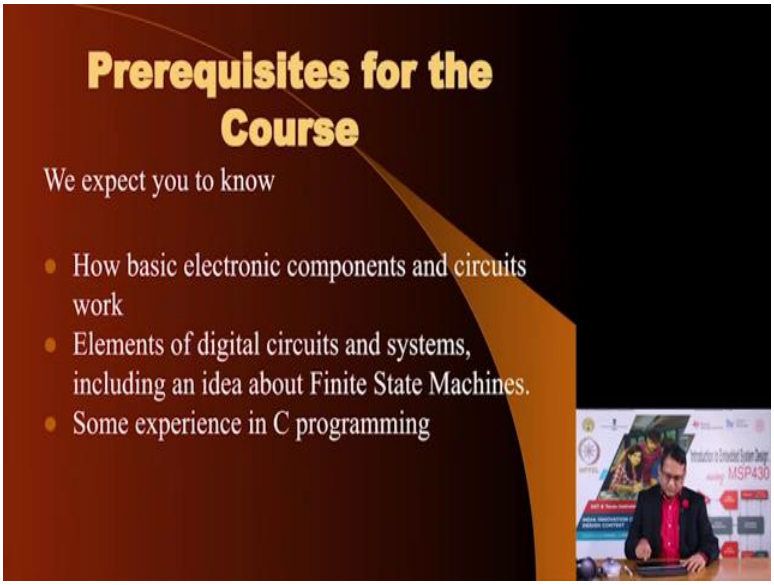


We expect you that you would be aware of basic electronic components and circuits that you are aware of how digital circuits work, how digital circuits system work and you have some idea about the finite state machine. It would also help if you have some experience in C programing and computer architecture.

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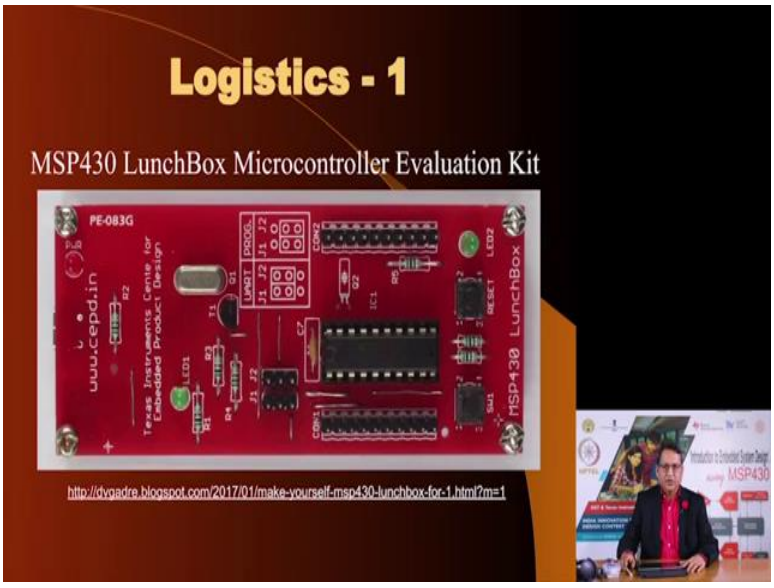


Beyond this let us talk about the logistics as part of the requirement of this course there would be lot of hands on activities during this course. And the hands-on activities will be around a MSP-430 evaluation kit which we call as the MSP-430 lunchbox, this as I mentioned has been

designed in my lab, selected and registered participants of this course would receive this kit for free. Beyond that we expect you to have certain common electronic components and here is a list of those components.

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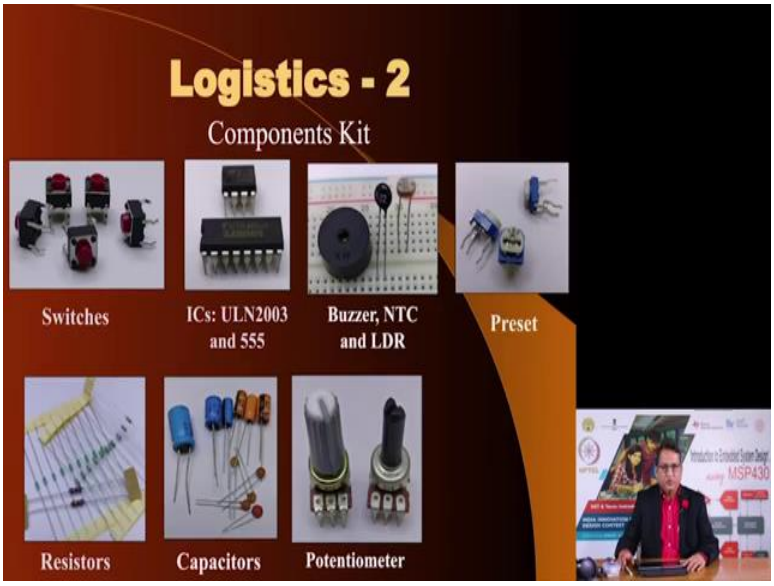


You may, you would like to, we would like you to have some switches, a few ICs, a driver IC called ULN2003 and 555 basic input-output devices such as a buzzer, a thermistor, an LDR which is a light detector, some presets, resistors, capacitors, couple of potentiometers and LEDs.

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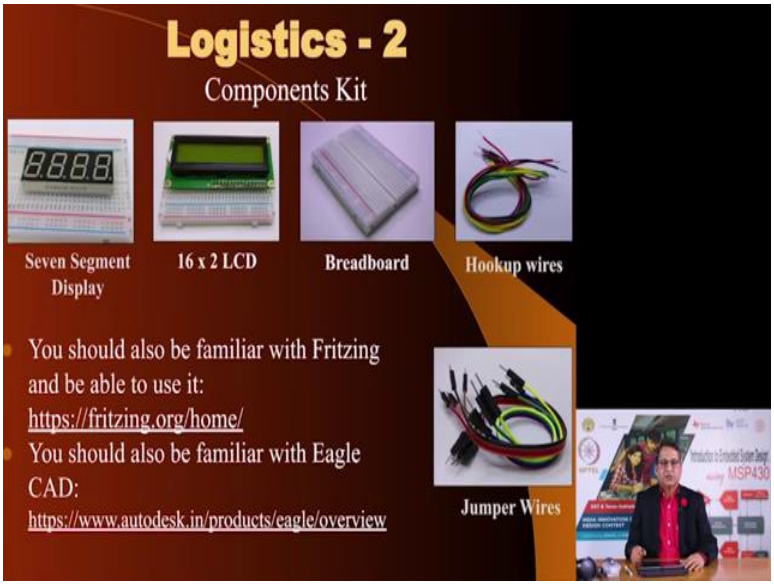


Beside that we would like you to have a 7-segment display, a liquid crystal display, a bread board on which to fabricate these circuits and also hook-up wires and jumper wires. Beyond these we expect you to be aware of what is called as fritzing, fritzing is a freely available software with which to create wiring diagrams.

Many of the experiments that we do as part of this course we will share the schematics on a fritzing method and we hope you would be able to use it and it would help if you are also aware of the Eagle CAD which is a schematic capture and PCB design software. This is, this covers the logistics of this course, now let us start with some of the definitions and characteristics of embedded system.

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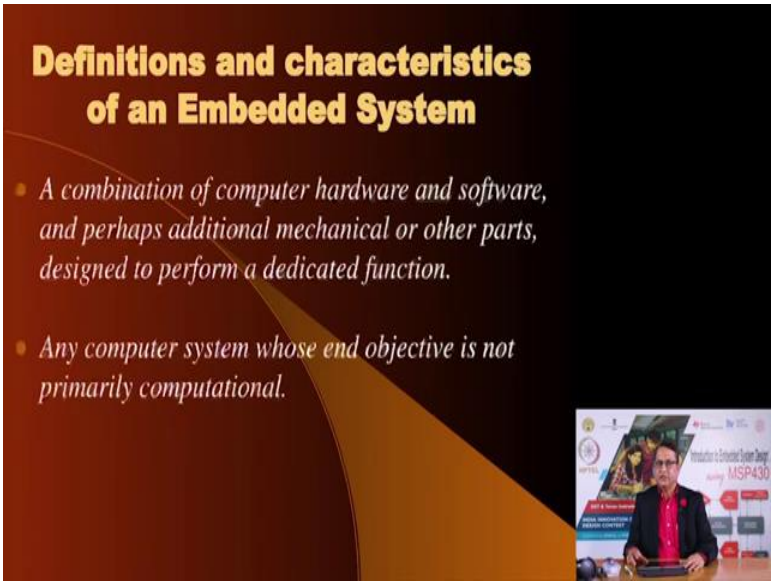


Now, embedded system is such a vast field and such a diverse field that it is very difficult to use a single definition to describe an embedded system in completeness. So, there are a few definitions and I would like to go through many of them. One definition is that an embedded system is nothing but a combination of computer hardware and software and perhaps additional mechanical or electro-mechanical parts with the purpose of providing a dedicated function. Another definition says that any computer whose end objective is not primarily computational would qualify as an embedded system.

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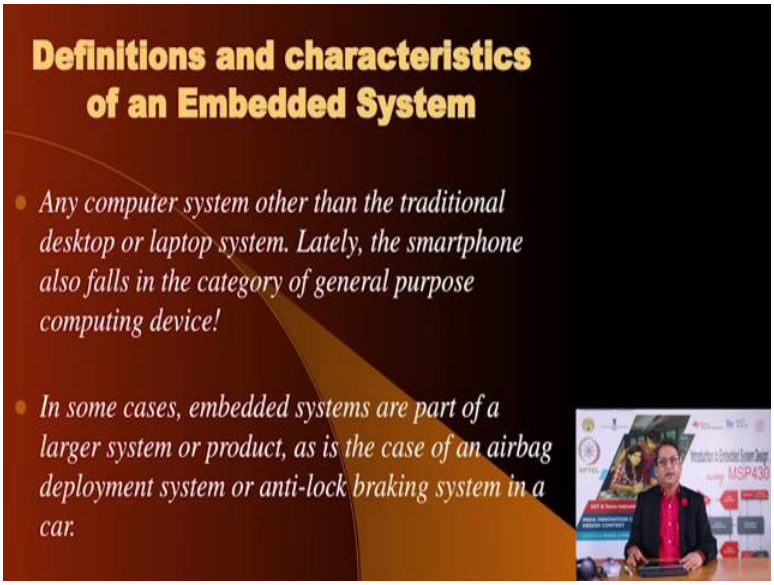


Yet another definition is a computer system other than the traditional laptop or desktop system would be an embedded system and in today in that list I would also add a smart phone because smart phone today people are using it for many-many diverse applications where they can also add to the applications.

Therefore, a smart phone is an example of a general-purpose computing system so anything other than a laptop, a desktop or a smartphone would qualify as a embedded system, any system which uses a computer but which is not any of these 3 is an example of an embedded system. In some cases embedded systems are part of a larger system and you are not even aware that you are using such a system and case in point is anti-log break system in a car or the deployment of airbag system in a car are examples of embedded system.

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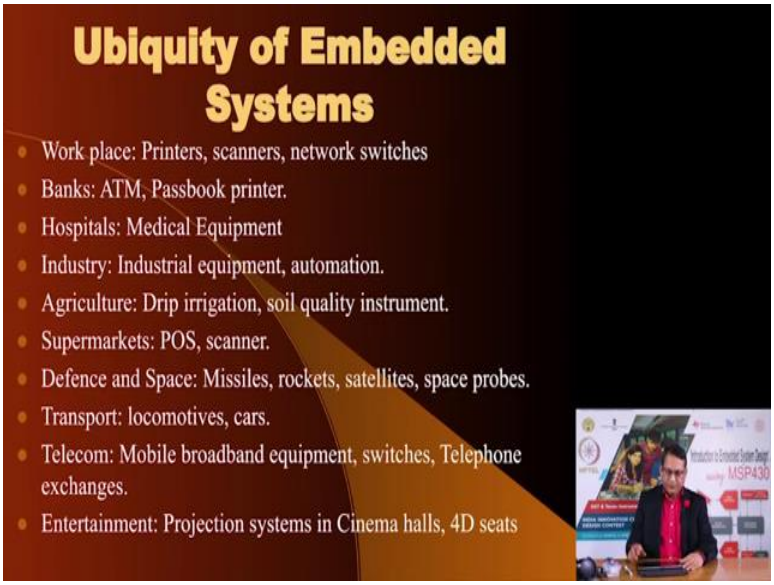


Okay, let us see how Ubiquitous the embedded systems are. In our daily life we encounter embedded systems at home, at work around us all the time and I have put together list of such devices at workplace we use printers, scanners, network switches in the banks we use ATMs passbook printers. In hospitals we have all kinds of medical equipments.

In industry we have industrial control systems, automation devices, we also have agriculture in which drip irrigation systems equipment to test this soil quality are examples of embedded systems. In the supermarkets we have point of sale terminals, we have scanners for scanning the commodities that you buy, we also have defense and in the area of defense and space, we have missile systems, we have rockets, satellites, drones these are all examples of embedded systems.

In transport we have locomotives, metro rails, cars. In the telecom sector we have mobile broadband equipment, we have switches, we have telephone exchanges and for entertainment we have projection system in cinemas halls as well as 4D seats where you seat and you get out of the world experience because as you watch a movie based on content of the movie the seat vibrates or it moves from side to side and so on and so forth. So, these are all examples of embedded systems.

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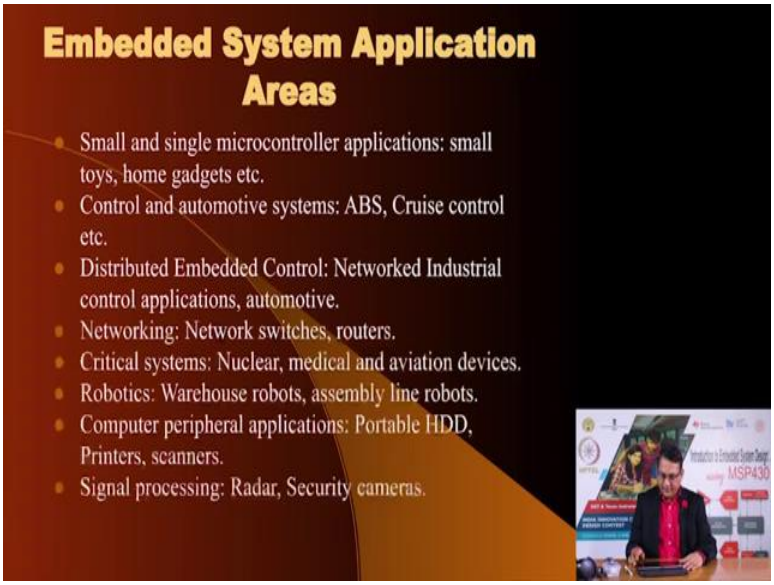


From a applications area point of view I have created a certain list, these embedded systems applications have several classification and one of them would be small and single microcontroller use whereas in an application you use a simple small microcontroller in fact the microcontroller that we are going to illustrate during this in this course would qualify in that category and with such a small microcontroller you can probably design small toys or gadgets at home.

Then we have control and automotive systems such as ABS that is Anti-lock Breaking System, cruise control system in a car. For distributed in embedded control another classification of embedded system you would have network, industrial equipment, you would have automotive applications then you have network in classification where all the network switches would fall in that category.

You have critical systems where the reliability of the system is very-very important and in that category, you would have nuclear power plants, you would have aviation the domain of aviation and in medical applications. Then you have robotics where you have warehouse robots or assembly line robots then computer peripheral applications where you have portable hard drives, printers and scanners and for signal processing applications such as RADAR or security cameras. These are application areas of embedded systems.

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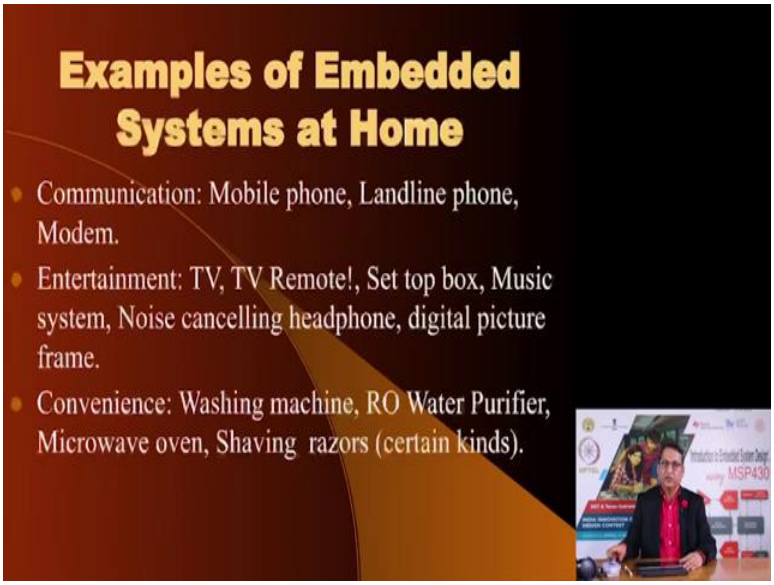


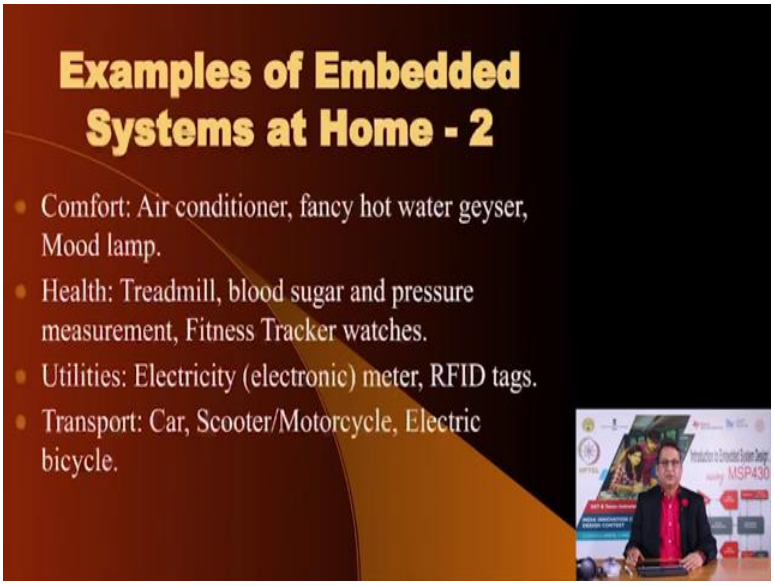


Now since we spend most of our time at home I have put together a list of examples in a typical middle class Indian home which are examples of embedded systems. For communication we use mobile phone, landline phones modem to connect to the internet for entertainment we have a television, a television remote a setup box to receive television programs, we have music systems recently this Sa Re Ga Ma music player became very, has become very popular.

Then you have noise cancelling headphones in fact I am going to talk more about it in a couple of slides. We have digital picture frames then for convenience we have washing machines,

reverse osmoses water purifiers, we have micro-oven, we have shaving razors of certain categories. Again I have an example which I will go through in little more detail.

Then for comfort we have air conditioners these days you get fancy water heaters where the heater tells you the conveys you the water temperature by changing the color. We have wood lamp then for health we have treadmill, we have fitness tracker devices, we have blood pressure measurement, we have blood sugar measurement.

For utilities we have electricity meters these days you may have no test that electricity meter at your home has a LCD display that is an example of embedded system. We have RFID tags again I am going to go through that example. For transport we use cars or motorcycles, scooters and increasingly electric bicycles and electric rickshaws these are all examples of embedded systems.

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Now, since I mentioned a few examples which are unbelievable that these are examples of embedded systems I have here this is Gillette Fusion proglide razor, it uses a battery for its operation and it has a microcontroller inside. In fact interestingly the microcontroller that is used in this razor is a MSP-430, I have shared the link for this webpage which you are describes which microcontroller in detail I encourage you to go through that. The reason why it uses microcontroller and that is why it is an example of an embedded system is as you use the battery and the battery gets discharged over time the, let me start again.

The way, the reason why it uses a battery is that the when you turn this razor on, the razor head vibrates apparently it gives you smoother shape. Now, as you would keep using the battery the battery voltage will reduce it will discharge and that will reduce the vibration of this razor. To maintain the vibration they use pulse width modulation, so as to maintain a uniform vibration over the lifetime of the battery for that you need this embedded computer.

Secondly there is only one switch with which you turn it on or you turn it off. When you turn it on and if you forget to turn it off it will auto turn off in about 8 minutes. And to do all this you need a embedded computer. So, this is interesting example of an embedded system application.

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The second example is this I have this Sennheiser noise cancelling headphones. Now, normal headphones are mere headphones but this one requires a battery for operation. Also, on of the cups there is a little hole there which is basically there is a microphone inside, what this does is it samples external sound that sound which is also leaking through the cups of the headphone and it enters you ears.

This noise cancelling headphones samples that sound produces an anti-phase version of that sound and mixes into the speakers in these cups so that you are actually hearing 3 sounds. The music that you are playing, the external sound that is leaking through the cups and entering your ears and the anti-phase version that this headphone is creating that anti-phase version cancels the

noise which is coming from outside and you hear only the music that you are playing. And so it gives a great example of an embedded system.

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And the third is this RFID card, we have taken it apart to actually show how where is the computer here, if you see I do not know if it is possible this is Delhi metro card and I heated it up to sort of strip the covers part and inside you see there is a bit of wire and little chip here that chip is the embedded computer and using this you are able to buy credit and store that credit on the metro network on this card and use it whenever you are travelling on the metro rail. So, these are all examples of embedded systems, interesting examples of embedded systems.

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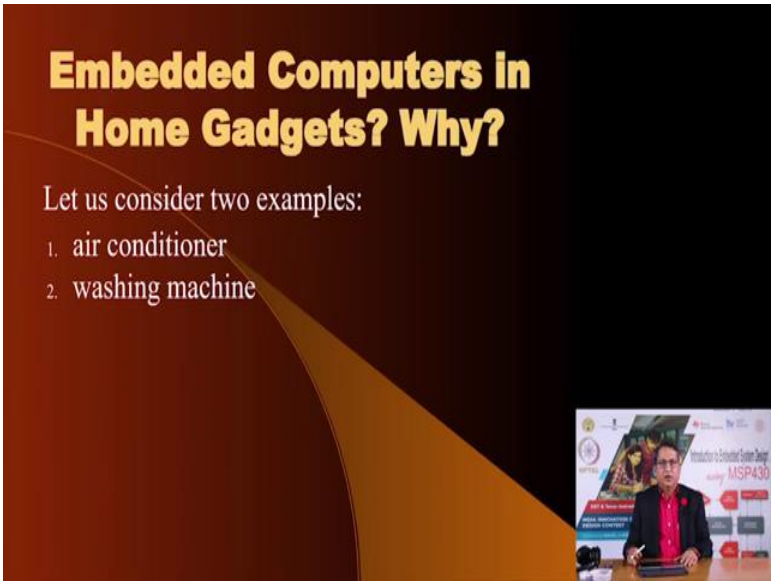


Now, the question arises that for gadgets at home why do we really need embedded computers? Do we need embedded computers? Is it possible that these gadgets can work without these embedded computers? Many of them did, in fact I am going to consider two examples, one is an air conditioners and the other is a washing machine to show that these two devices actually precede the development of a computer or the embedded computer.

You had washing machine or an air conditioner which did not require a an embedded computer. How did it function and how today we are, we have improved the performance of these devices by including an embedded computer and therefore today it makes a lot of sense to have the an embedded computer in an air conditioner or washing machine and likewise it goes for all the other gadgets at home. So, let me go through that with the help of a sketch.

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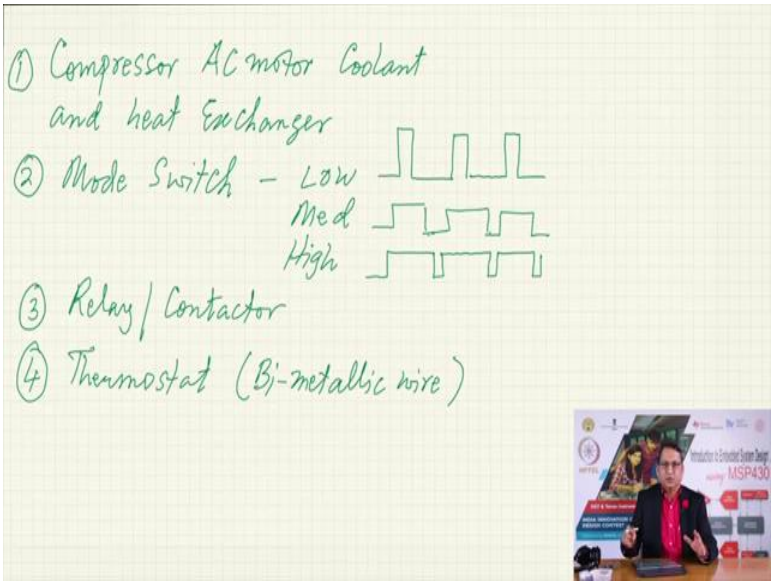


So, in an air conditioner the old style air conditioner what all things we had? We had a compressor which used an AC motor together with a coolant and heat exchanger, this was one of the things that you needed. Then you had a mode selector switch, mode switch which probably offered 3 modes of operation: low, medium and high cooling. 3, you had mechanism to turn the compressor on and off with the help of a relay.

Often times it will also called a contactor and 4, you had a thermostat and in the olden times it used a bimetallic wire type of thermostat. Now, with the help of these 4 devices user would select how much cooling they wanted in low cooling the compressor would be on for small period of time and it will turn off and then after sometime it would turn on again and then it would turn off on and so on.

Now, ofcourse if the thermostat indicated that the temperature that the user desired has been reached it would turn the compressor on earlier. In the medium mode it would turn the compressor on for a longer duration of time and so on so that you could get higher cooling and so on. And in the high mode it would turn on for much longer so that it would cool even more than the other settings and so on and so forth.

And in this mode you did not have much choice about the temperature you wanted the air conditioner to give you in that room. Now, let us add a embedded computer to this and let us see how things have changed overtime.

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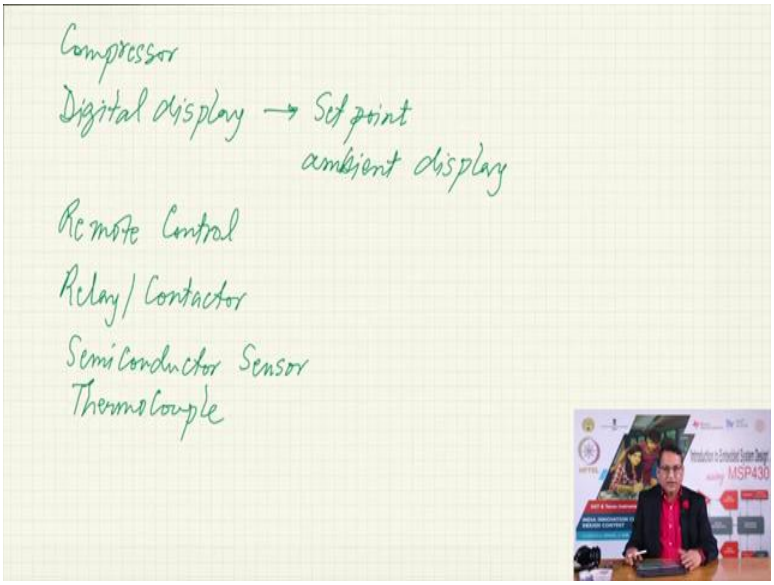


Now, the compressor part remains the same you still have you need a compressor with AC motor and all that but now you expect a digital display on the air conditioner which indicates the set point you would you can set what temperature you want the AC to operate at so it will allow you to show set point temperature.

And after that as the air conditioner starts working it will display the ambient temperature so it has ambient temperature display. Now you wanted to do all this without touching the air conditioner, so you wanted remote control for that. Now, instead of 3 settings low, medium, high you have wide variety of settings you can set the temperature to 20 degrees if you want or 25 degrees if you want.

Also it would have some modes where you say okay I want to have a night mode when you go to sleep you do not want the AC to cool as much. So, the air conditioner would cool less. Once you select the night mode of operation, also it has the same relay or contactor and for the temperature measurement it uses a semiconductor sensor or a thermocouple.

And so given the additional feature that you expected the air conditioner to offer it was imperative that you embed and a computer in the air conditioner as to offer all these features. So, having embedded computer in a air conditioner to get better performance is quite justified. Let us take another example and that is a washing machine. I am going to start with the washing

machine example that was there before embedded computers were included in them and what all you had?

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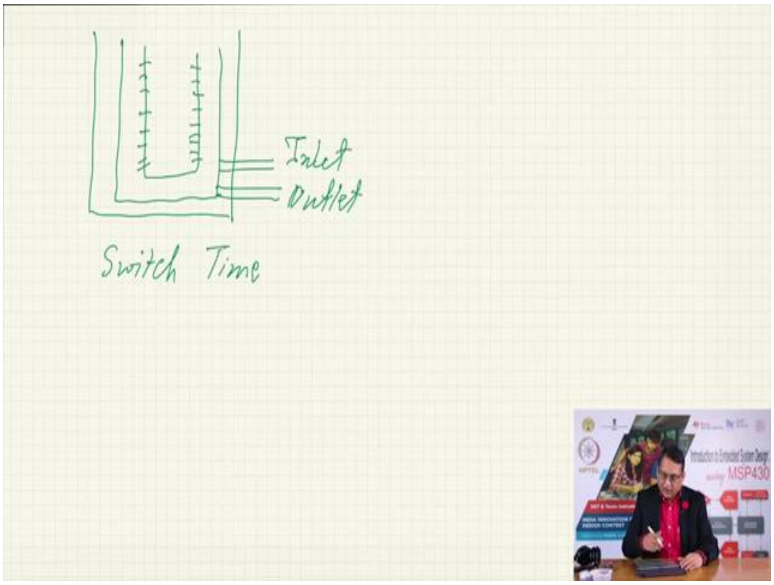


You had a outer enclosure which is the main enclosure, you had a middle container and then an inside container. In the middle container here you would have 2 pipes, one for inlet of water and one for outlet and you would have a selector switch to select how much time you want the machine to operate and the inner container had holes so that you could fill it up when you are filling the middle container with water that water enters the inner container wets the clothes and then there is a motor which is usually a AC or a universal motor to spin the innermost container.

And you had absolutely no other control over it, you would put clothes in it and you would run the machine and at the end of that washing cycle you would inspect whether the clothes are clean or not. Maybe if they are not clean and if the clothes are cotton you might add hot water in this cleaning process and so there was lot if iteration you had to do to get your clothes really clean. Then you add, then comes the modern times where you can add an embedded computer. Now what do you have?

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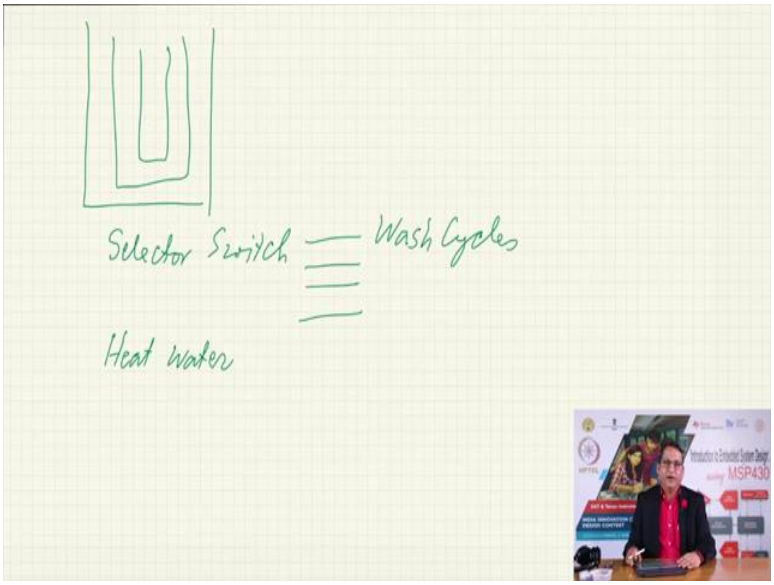


You have the same structure pretty much that an inner and a middle container and then you have instead of just a time setting you have a selector switch which allows you various modes of operation what we call as wash cycles. So, you can select oh do you want to wash silk clothes or do you want to wash cotton clothes, if you have selected cotton clothes your modern washing machine would also have a mechanism to heat water.

It would also include display to indicate what modes you are selected, it would have a mechanism to sense whether water is optimally filled in the washing machine or not. It would have a dirt sensor so that when you rinse the clothes and the dirt of the clothes is apparent in the water it would know should the washed cycle be performed for half an hour or 50 minutes alright.

And to do all this obviously you need a microcontroller or an embedded computer to achieve this performance. It would also give you a facility that if you wash cycle is to happen for 50 minutes and unfortunately if the electricity goes off and when the electricity resumes it would know how much time it has already spent and it would only run the machine thereafter for the left time instead of starting all over again. And so to give you all these features is only possible when you embed a computer in a washing machine that is what is happening in a modern washing machine. Let us go back to our presentation.

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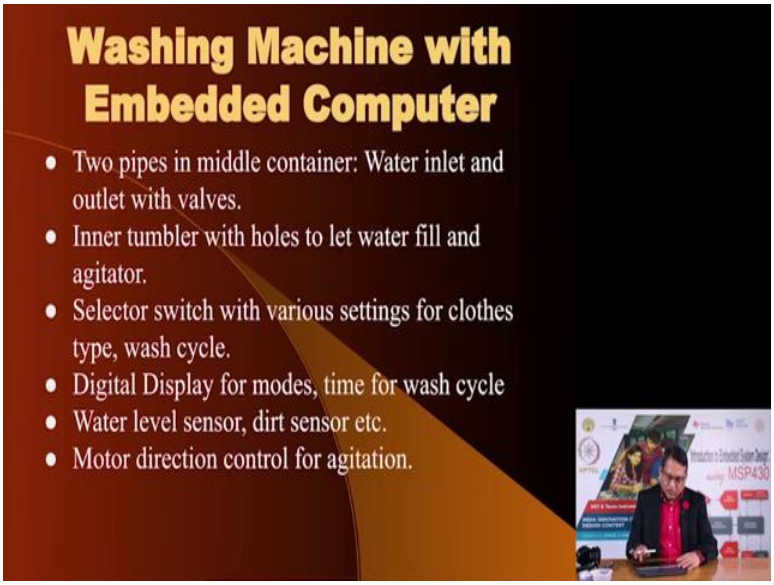


So, we have justified that having embedded computers in these home gadgets give you better performance more efficient devices, more user friendly devices and so they all justified.

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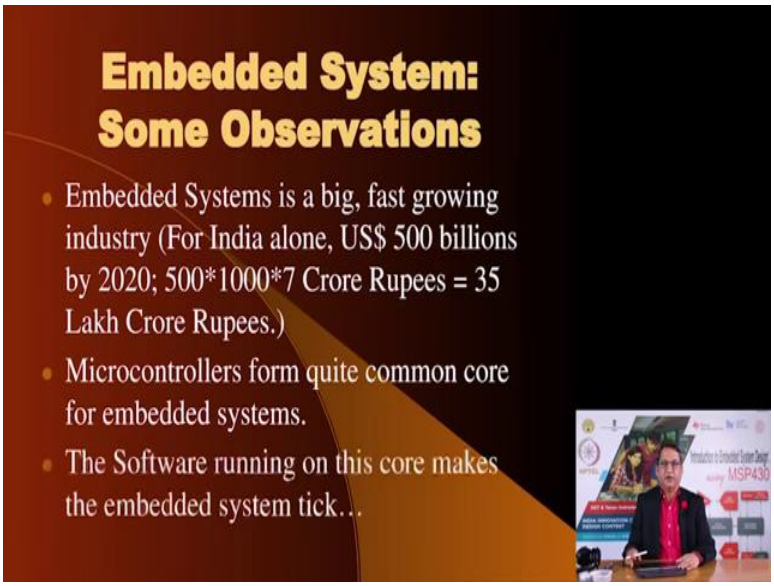


Let us now let me share some observations. One of the observations is an embedded system just because of the Ubiquity of embedded applications embedded system is a big and fast growing industry. It has been estimated that for India alone this year in 2020 we would be looking at something like 500 billion Dollar worth of equipment.

Now obviously who are going to satisfy all these requirement? You, the engineer in works you when you graduate if you all the skills you can get jobs in these areas or you can be one of the persons who creates designs bids the next generation embedded application. Microcontrollers are one of the common features of implementing embedded applications and which is the reason why we are going to include a microcontroller in our course. Ofcourse microcontroller is only the hardware without an appropriate software running on this microcontroller, it is not possible to have a efficient embedded application.

Not just efficient it is not possible to have an embedded application without the software, so it is very important that we teach programming such devices in appropriate fashion so that real value of these embedded applications can be brought out.

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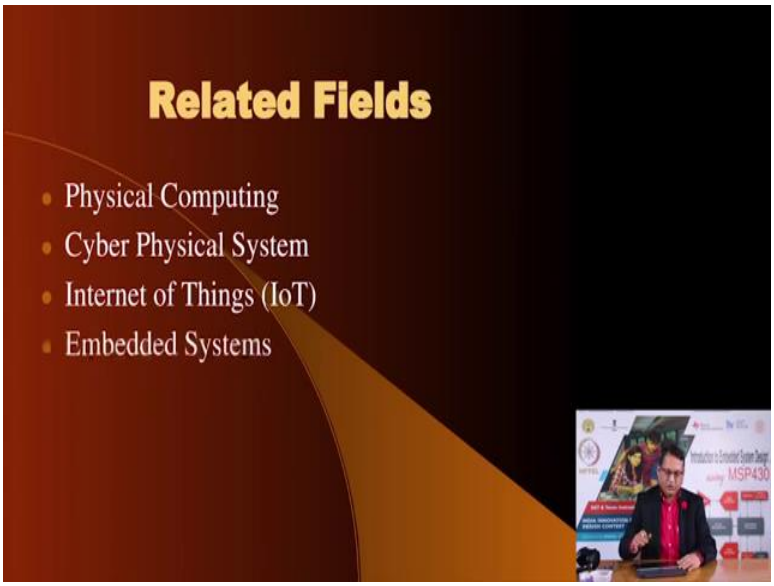


Now, apart from embedded systems as a term there are couple of other terms which are going around which have become very popular they are related to embedded system so I find it pertinent to discuss them. The first term is physical computing, physical computing is described as any computing system which is aware of the physical environment which means a computing where it can sense the environment, process that information in that program and then produce an output so as to control or visualize or present the outputs. So, it is a very generic term.

The second term which is becoming very popular is called cyber physical system. Cyber physical system means as the cyber term indicates that the physical systems are connected, distributed in

space and they are connected with some sort of network. The important point to note here is that network need not be internet. It could be internet but there is no necessity, it could be a private network.

And the third term that is becoming common is called internet of things. As the important word, here operative word here is the internet IOT types of devices are a subset of cyber physical systems in that, that they necessarily use the internet. Internet is a common resource available to anybody on this earth and therefore devices that use IOT are a subset of cyber physical systems, they allow the humans to interact with their these gadgets over the internet. And ofcourse the embedded systems. So, I am going to draw a Venn diagram to indicate the relative position. The most common term is ofcourse the physical computing.

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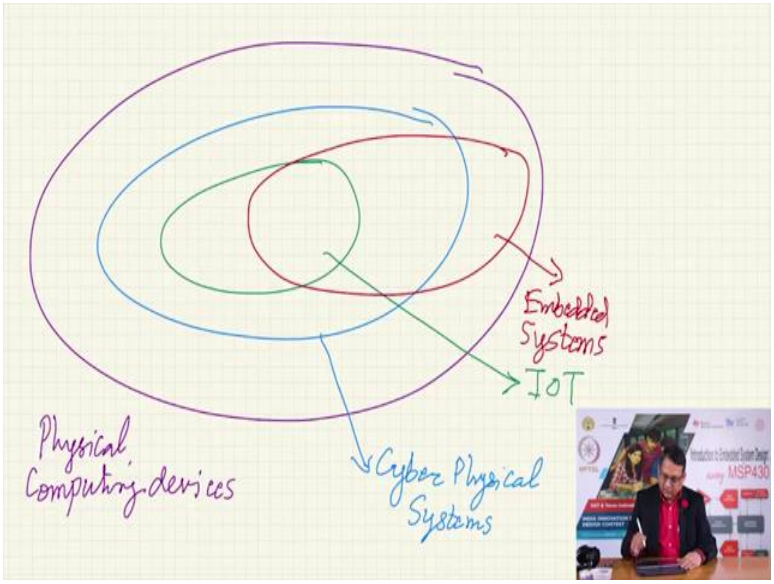


So, let me draw a circle the biggest circle to indicate physical computing devices. It is a generic term that means any computing device which is aware of the physical environment is able to sense the environment, process that information using a computer program and then output some useful result it could be to control an actuator or may be to plot some diagram, plot some maps or something like that.

Since there is no restriction on the physical form of that computer it could even be a desktop computer. A desktop computer does not have any mechanism to sense the environment but you can attach a bunch of sensors through the USB port which is a common connectivity option on a

desktop computer and then you write an appropriate application program on your desktop computer.

You can convert the a desktop computer into physical computing device but this is not an embedded system because you cannot carry it around it is a general purpose device where you are using it for this specific application of physical computing. Then as a subset of physical computing devices you have cyber physical systems that as the term indicates there is connectivity between devices which may be distributed and what are examples.

Autonomous vehicle is an example of cyber physical systems, remotely piloted drone is an example of cyber physical systems. In this particular case it may not use the internet at all it would have a its own dedicated may be through satellite or something like that to remain in good control of that drone. So, that is an example of cyber physical system.

Then I would have a smaller subset of this which I call as an IOT device and what is a, what would be an example of an IOT? May be these days you get reverse osmosis water purifier systems at home, now these are suppose to filter water but how long the water purifiers continues to work without servicing will depend heavily on the quality of the water.

If the water quality detoriate these filters would clot and they would stop providing you with clean water and you would require them to be serviced before you could use it and that is where introduction of a IOT device into IOT system into the water purifier would make it much more user friendly, why? It would keep on sensing the quality of the dirt that has been accumulated on these membranes and would send a message to the service provider, who would alert you that your water purifier is going to stop working in a weeks time.

And therefore it would be prudent to do what is called as preventive maintenance so that you continue to receive good quality water without any disruption, so this is an example of IOT and last but not the least we want to put our embedded system in this. Now, because there is no necessity that the embedded system should have some connectivity therefore, I would draw a circle like this to indicate embedded systems.

And ofcourse all the examples that we have seen are embedded system examples and so these are the 4 terms related terms and it is important that you as a participant are aware of it. We are

going to take a short break here and we will resume our discussion from this point onwards which would be to compare embedded systems and general purpose computing systems, see you in a bit, thank you.