Embedded System Design with ARM

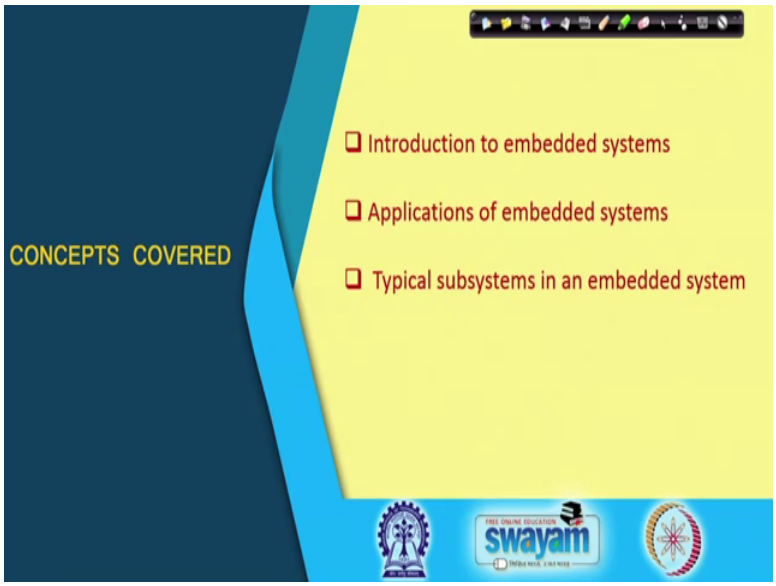
Prof. Indranil Sengupta
Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

Lecture – 01
Introduction to Embedded Systems

Let me welcome you to this course which will be conducted jointly by myself and Dr. Kamalika Datta. Now, in this course we shall be talking about various aspects of Embedded System Design, in particular we shall be emphasizing on some hands on design examples. And as the vehicle of demonstration we shall be primarily working with two different you can say embedded system platforms; one is based on an arm based board that is an arm cortex m for base board and the other one will be a standard Arduino Uno based board.

Now before we proceed with the actual experimentation, it is always good to have some theoretical background and some motivation behind why we need an embedded system, what are the main characteristics of an embedded system and what are the design alternatives. So, in this context the first lecture of this course, this is titled Introduction to Embedded Systems.

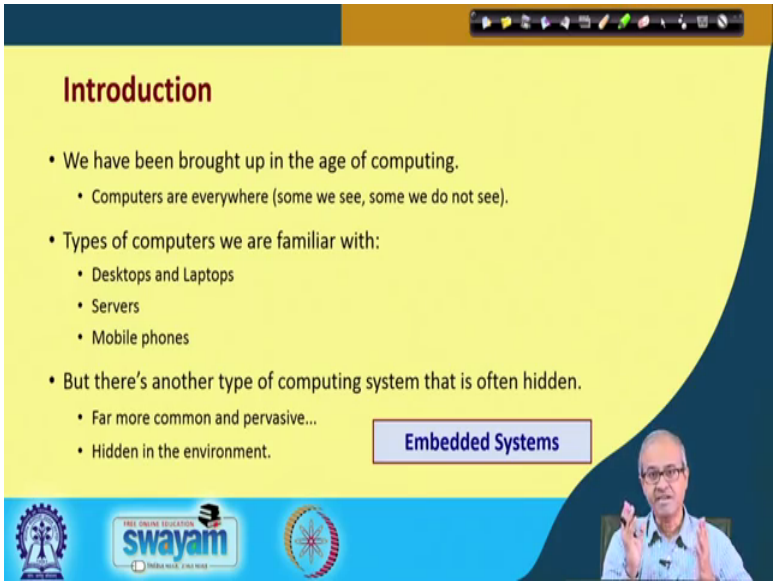
(Refer Slide Time: 01:40)



Here we shall be primarily talking about embedded systems what it is basically and some typical applications and inside an embedded systems, what kind of typical subsystems

we normally get to see. These are a few things that we shall be discussing as part of this course.

(Refer Slide Time: 02:05)



So, let us start with our discussion. Now the first thing I want to emphasize is that, well this is a very important point, well we have been very lucky you may say lucky in some sense, that we have been born and brought up more of us in an age of computing. Since our birth many of you have seen computer systems around you, but of course, the scenario was not the same maybe 4 or 5 decades back.

But there has been a fantastic proliferation of electronics computing systems, low power devices and there are various kind of kinds of advancements that have taken place over the years. So, the first thing I want to emphasize is that, computer systems are everywhere today. So, if you look around you; well I am not talking about in a technical environment, not in your laboratory, not in your college well even in your residence when you wake up from your sleep.

So, if you look around you, you will find several instances where there will be some computational devices that will be sitting somewhere. This is the kind of environment where we have all grown up. Now traditionally speaking, we have become familiar with computers which are either desktops, laptops, servers these are the kind of computers which are more conventional in some sense. Desktop computers are typically machines where you have learnt or computing on. Today laptops have become very much

affordable, most of us own our personal laptops. So, laptops are replacing the role that desktops used to have earlier. Talking about mobile phones this is a very very underestimated computing device.

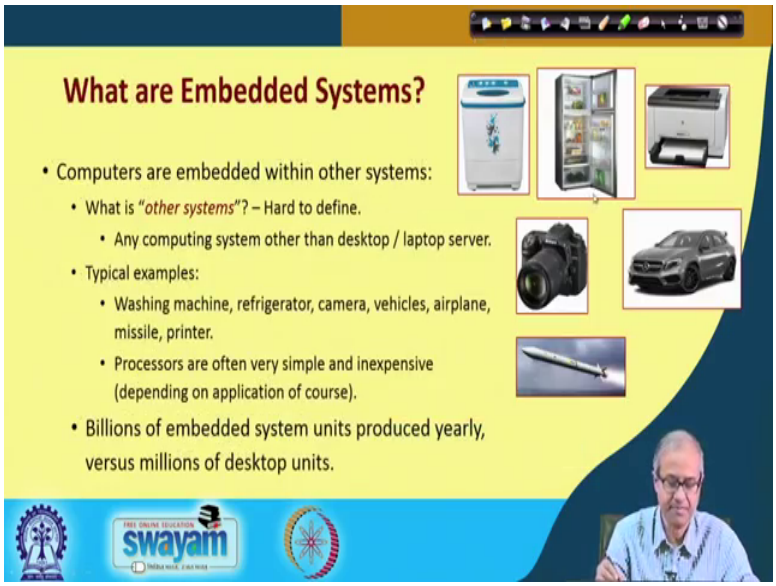
So, whatever is inside a mobile phone today, if you think of the computational capability of the computers that existed 30 to 35 years back, believe me the processes that are inside a mobile phone are of the tune of 1 million times more powerful as compared to what you used to see in the large computer systems in those days. But well mobile phones we use for some specific applications for of course, for its use as a telephone sending messages. And of course, for recreational purposes we can watch video we can browse internet and there are so, many new applications that you can run out on mobile phones today right.

But what I want to say is that, there is another kind of computing system that is often hidden from us. Hidden means we cannot see those computing systems. Like we know desktop can compute, a laptop can compute, a mobile phone can also compute in some sense. But if you look at a refrigerator, if we look at our air conditioning machine do they look like a computing machine? No. But inside those machines there is some computing brain hidden that is what I am referring to as this hidden thing. These are far more common in our daily life and pervasive they are everywhere, and the point I want to make is that, they are hidden in the environment for which they were created ok.

Now, such systems are traditionally referred to as embedded systems. We mean these are computing systems, but they are embedded inside the environment well by the term environment we mean the surroundings or actually the scenario for which the system was designed. Let me take the example of an air conditioning machine again, well an AC machine is supposed to be housed inside a room right normally. Now this computing system that is sitting inside an AC machine for that computing system the AC machine is the environment. So, it does not interact with anybody outside that AC machine.

So, it is responsible for controlling the AC machine, it is responsible for responding to whatever you are pressing on your remote control, you are given giving some commands to the ac machine and so, on ok. These are the kind of commands that those computing machines inside are responsible to respond to.

(Refer Slide Time: 07:47)



Now, talking about this embedded systems again, what are these embedded systems? I already gave an example. So, now, it must be somewhat clearer to you. Embedded systems are computers they are embedded within other systems. Now on the right side I have given some pictures you see these examples here you see and this is a washing machine, this is a refrigerator, this is a laser printer, this is a digital camera, this is an automobile and here you can see a missile that is flying through the sky. These are all examples of embedded systems, they are fairly powerful computing systems or devices inside them of course, the power of these computing systems depend on the specific applications.

For some applications you do not need too much computation power, but for a system like missile lot of computations need to take place in real time. As the missile flows in its trajectory, there is continuous feedback from the environment and there are some corrective actions that need to be taken such that the missile can follow the correct path and hit the target in a precise way.

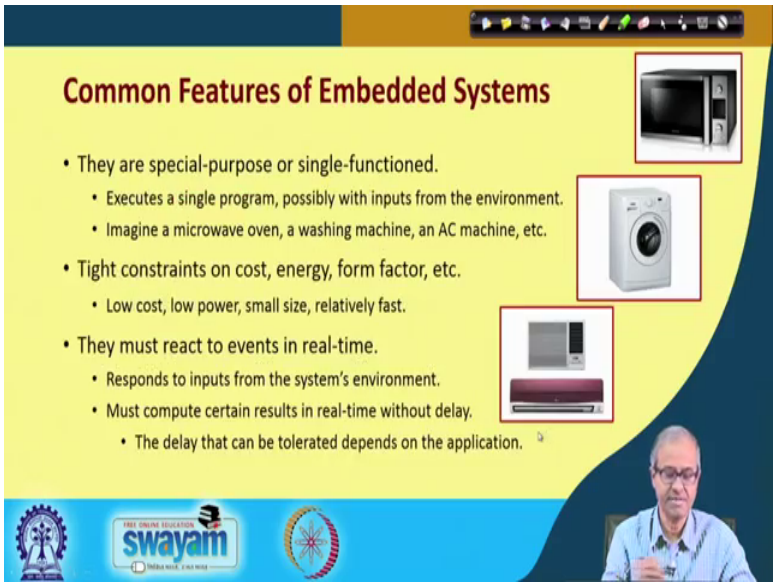
So, it depends of course, on the environment. Now this other systems embedded; well these other systems as it said this can refer to anything it is very hard to define in a very specific way. But broadly speaking you can say that these other systems are any computing systems, which are not our conventional computers desktop, laptop, servers etcetera.

So, any computing systems which are not one of these, they are sitting somewhere and working with the environment, they can be classified as embedded systems ok. Some typical examples are given here the pictures are shown here of course, washing machine, refrigerator, camera, vehicles there can airplanes also a very big example, missile printer. And again just as I said depending on the application, processor can be very simple and inexpensive. Because there are many devices let me take an example again suppose you have gone to the market to buy a microwave oven, well microwave ovens are available for prices ranging for rupees 3000 and more.

So, they are pretty cheap in comparison. So, there are embedded processors inside micro ovens also. Now if I say that, I need a very powerful Pentium processor to be sitting inside a microwave oven the price of that Pentium processor itself will be 5000 rupees including all accessories and other peripherals, then this will be economically not viable. They have to be very cheap depending of course, on the applications. But if you think of a missile, there the computing system can be a multi lakh affair because the price of the missile itself is very very high.

So, the price of the computing will be a small fraction of that it depends on the environment on the application. So, today a very large number of embedded systems are being used all over the world in various applications, billions of them versus millions of conventional computing units. So, in terms of just the numbers, the number of such embedded computing devices far outnumber the number of conventional computing devices today.

(Refer Slide Time: 12:13)



So, there are some common features which are present in most embedded systems let us look at some of them. First thing is that, they are special purpose or single functioned single functional. Like an air conditioning machine, there is a processor inside, the sole purpose of that processor is to ensure that the ac machine is working properly nothing else. So, it is not trying to help you in calculation in doing some maths and so, on.

So, it is very special purpose in that sense. So, it typically it executes a single program related to the application for which it was built right and it can take inputs from the environment. So, what do I mean here? You think of an ac machine the inputs from the environment means, well the user can send some commands via the remote control. The ac machine itself can have some sensors inside it consents what is the current room temperature what is the current humidity level. So, accordingly it can activate the various subsystems inside in a very optimum way. You think of a refrigerator there normally there are some control panels.

So, you can set the temperatures and other factors there. It depends again on the application, the environment through the environment you can send some commands to the processor the processor will respond accordingly right. So, some examples I have given microwave oven, washing machine, ac machine these three pictures are shown here microwave, washing machine, ac machines. And most of these embedded systems again not all I am not considering examples like a airplane or a missile where computing

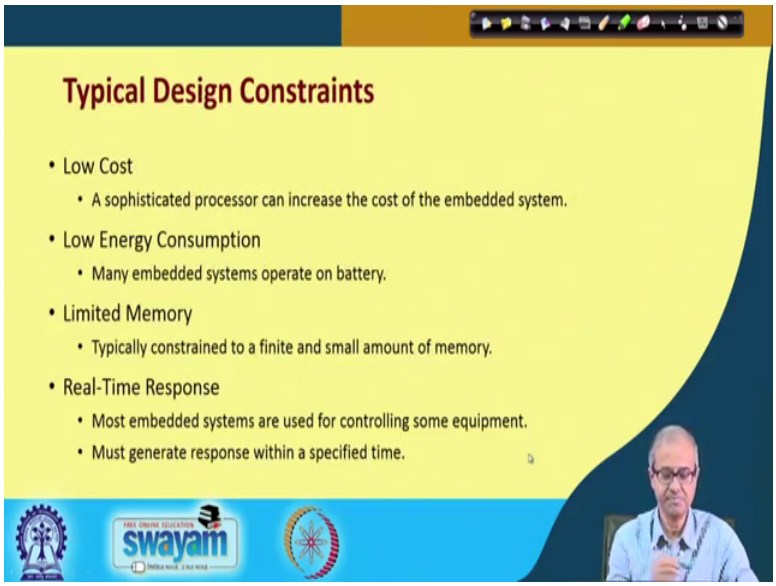
is very important and you can afford to have a multi lakh computing machine inside them, there is no harm there.

But you think of the normal household gadgets? There is very tight constraints on cost energy and also form factor cost is obvious. So, the processor has to be low cost otherwise the system will not be economically viable energy. Well the processor must not consume too much energy from the power source or from the battery wherever it is working. Because the processor is hidden from you and it is expected that the user should not worry too much about well the processor is consuming too much energy, my electricity bill is going up things like that. Form factor; you think of an ac machine nowadays ac machines are very sleek, now you cannot afford to have a computer inside which is very bulky and big because that will make your system also bulky and big.

So, depending again on the system your computing system must be made very compact and should fit inside without any appreciable increase in area right. So, low cost low power small size relatively fast these are some of the characteristics and another important is that it should have real time response. You think of ac machine, suddenly due to some reason the temperature of the room has gone up. So, it must turn on the compressor at high power to bring down the temperature.

So, it must respond to these external inputs in real time, it cannot say that well I shall respond to this after 10 minutes. It cannot do real time means, whenever an input comes within some specified time the system should respond to that input most embedded systems respond in real time. They take inputs from the system environment and should carry out the computations; well without delay is a subjective term the tolerable delay varies from application to application right. So, these are some of the common features.

(Refer Slide Time: 17:19)

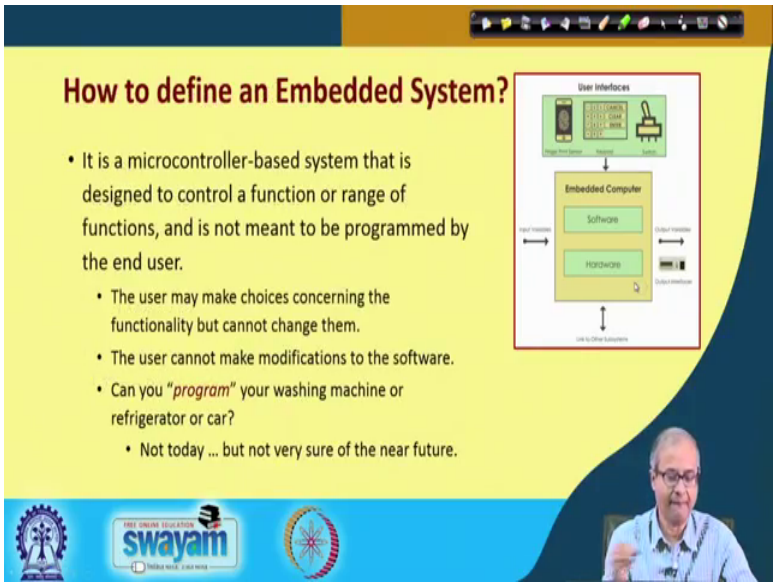


Now, there are some design constraints as well; some of these are pretty obvious the processor should be a low cost thing. So, you should not make it too expensive because that will also make your system inside which it is embedded, it will make that also quite expensive right. So, the processor must be low cost. So, you cannot afford to use a very sophisticated processor inside such a machine; like inside a microwave you cannot afford to put a sophisticated processor like the Pentium, because the cost of the Pentium itself is pretty high right.

Low energy consumption is another property which is pretty common. Well even for machines which operate from electric power, like a refrigerator if you put it on and go away, it is expected that it will consume very low power; well and secondly, there are many gadgets which also operate on battery.

So, for them obviously, power consumption or an energy consumption is a big issue right and because these processors are very simple, the amount of memory they have is also pretty small limited memory. So, whatever program you write whatever computation you do they must fit inside that limited memory space that is in a constraint and this already I mentioned many application demands real time response within a specified time, the system should respond to the inputs.

(Refer Slide Time: 19:09)



Now, how can we define an embedded system based on whatever we talked about so, far? Well embedded system can be loosely defined as a microcontroller based system. This is true for most of the embedded systems. The processor that is inside I said it has to be low cost it has to be low power, it has to be smaller in size. There is some kind of processor called microcontroller which we shall be talking about throughout this course they satisfy all this criteria.

So, most of the embedded systems they have microcontrollers inside them, they are like a complete computer inside a single chip. So, whatever you need processor memory is some I O everything is inside a single chip and therefore, it is very low cost. So, it should be a microcontroller based system and this is not general purpose it should control a function or a range of limited set of functions. And another point is that, this is not meant to be programmed by the user. Like a laptop or a desktop you can write a program, well you can write a program to compute the factorial of a number to find the sum of n numbers etcetera.

But whenever you think of an embedded system inside a device like your ac machine. So, you normally do not use it for your day to day computation, you cannot program it yourself. It comes to you factory programmed you cannot modify the program, it is a fixed program system you are only using that program you are running that program this is the idea.

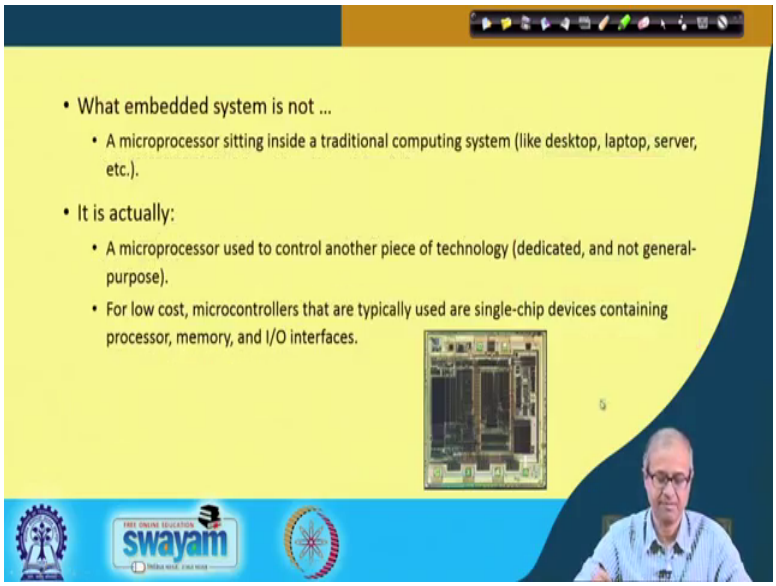
So, the user can make choices like user can give inputs for example, through the remote controls, but cannot change the functionality you cannot change an ac machine to something else a room heater for example, ok. The user normally cannot make any modifications to the software, but of course, well nowadays systems are became they are becoming more sophisticated well you think of a set top box that you use with your TV sets.

Set top box are also embedded systems there are quite powerful processors inside them. Now sometimes you may have noticed that while watching some programs or when you are switching it on, sometimes it says downloading updates. Well the software that is running inside the set top box that also gets periodically updated by the service provider. So, that facility is provided inside that set top box. Just like your standard operating systems like windows which frequently needs some updates to be installed ok.

That means, you need some modifications to your existing software to make it better in some sense. So, to talk about it normally you cannot program your washing machine or refrigerator or a car, but maybe tomorrow with the next generation embedded systems coming, you may be able to program them also. Like when you drive a vehicle you may program it and customize it according to your need, but as of today the systems come with very limited choice to the users; may be a few things user can specify, but not all ok. So, this is a schematic diagram of an embedded system you can see here. So, the embedded computer is sitting in the middle, which has some hardware the microcontroller and some program which is running on its software.

So, it takes inputs through some sensors usually and it can control something through some outputs and there are typically some user interfaces like some switches, some small keyboards, like some touch sensors maybe a remote control these are all user interfaces and it can also have some links to other subsystems and depends on the system of course,. So, this is a general schematic of an embedded system.

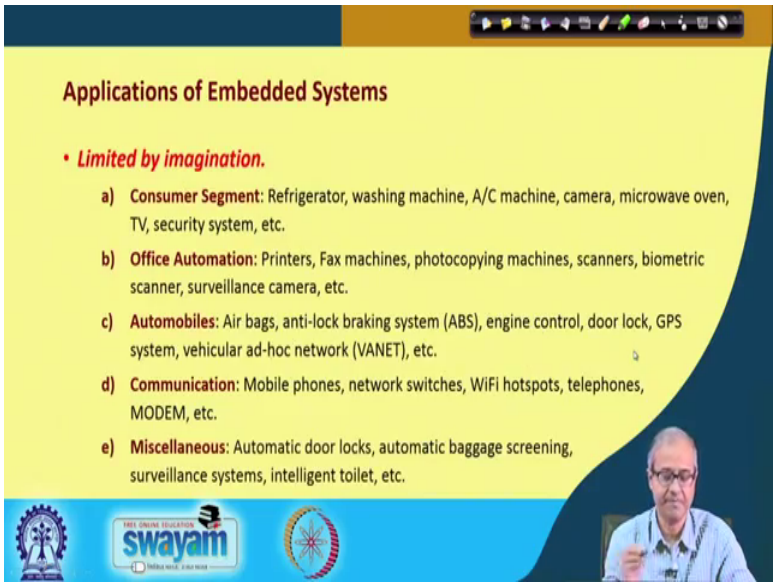
(Refer Slide Time: 24:09)



Now, what embedded system is not? Well it is not a microprocessor sitting inside a traditional computing system no it is not. We call it a computer we do not call it an embedded system right. Well it is a microprocessor used to control another piece of technology like SA machine, like microwave like refrigerator and so, on this is what an embedded system is.

It is embedded inside some other system ok. Now as I had said for low cost microcontrollers that are used they are single chip devices this I have mentioned. You see here I have shown a picture of a microcontroller that belongs to the pic family. This is a pic microcontroller this is a layout diagram where processor, memory, I O subsystems everything is embedded inside the same chip.

(Refer Slide Time: 25:17)



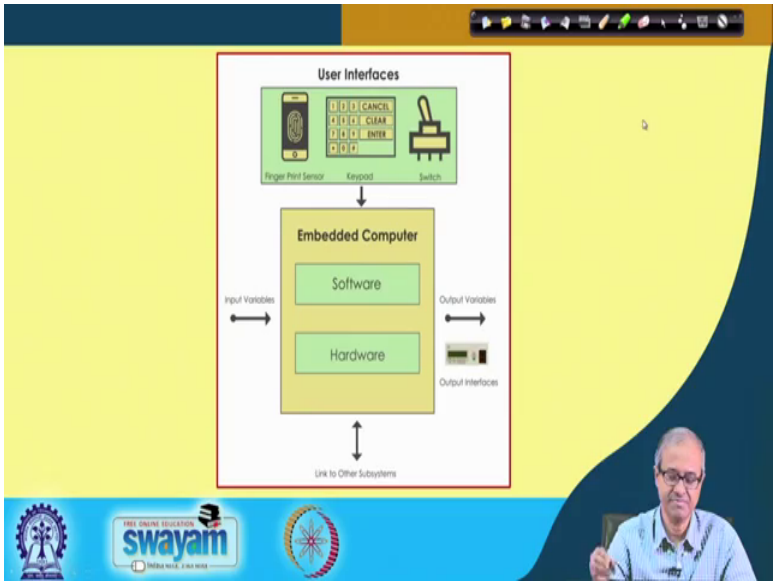
Now, talking about some applications of embedded systems you can summarize some of them, but they are limited by imagination there is no limit to what you can imagine. And the number of such applications will only increase day by day, today we are talking about internet of things IoTs tomorrow IoT this will be everywhere maybe some of those devices will be inside your body, you will be carrying those devices along with you.

You see in the consumer segment you can think of refrigerator, washing machine, AC machine, camera, this already we have talked about TV. Now even in your office you use printers and fax machines, photocopying machines, scanners, biometric scanner etcetera cameras for surveillance they are all examples of embedded systems. You think of automobiles today all automobiles are intelligent in some sense, there are some computational devices which tries to utilize the infrastructure inside those automobiles in an efficient way fuel efficiency engine efficiency and so on.

So, airbags anti-lock braking systems, engine control, door lock, GPS; so, everything here these are controlled by embedded processors. Talk up communication the mobile phones is the biggest example you think of the network switches that we use for communication routers, switch is then the Wi-Fi hotspots telephones there are processors inside each of them today. Then you can have automatic door locking systems we see it many places; well here automatic baggage screenings in airports and railway stations surveillance systems well in some places you can say intelligent toilets, where there are

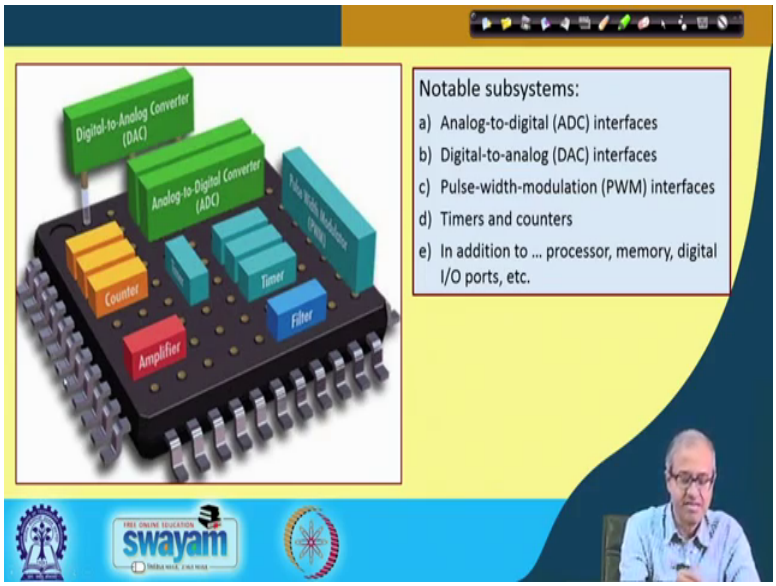
some embedded systems inside toilets also which can respond to users needs automatically these are all examples of embedded systems.

(Refer Slide Time: 27:29)



So, again talking about that diagram, this is what embedded system looks like. We have to have an embedded computer with some hardware you have to write some software to do it and of course, there has to be a proper user interface to make it usable. And user interface has to be simple enough it should not be a full big large keyboard where you can type anything and everything no. It will be very specific to a particular application you can use this.

(Refer Slide Time: 28:02)



So, this is just like a cartoon I am showing, this rectangular box is a processor for inside the processor you can see so, many things. You can see a digital to analog converter, you can see analog to digital converter, counters, timers, pulse width modulator so, many subsystems. So, in addition to processor, memory, I O ports etcetera a typical microcontroller today which forms the heart of an embedded system can contain analog to digital interfaces, because most of the inputs from the outside world sensors are analog in nature, they are continuous in nature like temperature humidity pressure etcetera.

Digital to analog interfaces for controlling some external parameters. Pulse width modulation interfaces we shall be discussing about them timers and counters. So, there are all of these things which are required for certain scenarios or the other, typically in those microcontrollers all these facilities are provided ok. So, with this we come to the end of this lecture we shall be continuing with our discussion in our next lecture.

Thank you.