Real-Time Systems
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Module No. # 01
Lecture No. # 01

Good morning and welcome to the course on real-time systems. Today, we will have some introductory discussion on real-time systems and we will see what the topics are and so on. Possibly in the subsequent lectures we will discuss these topics in more detail.

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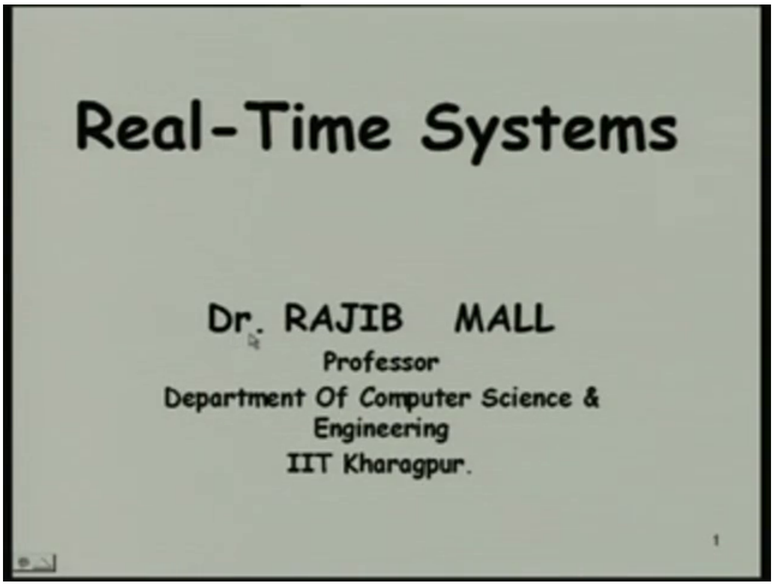

Let me just introduce myself. I am a professor at the Department of computer science and engineering IIT Kharagpur, been with IIT Kharagpur for last about 16 years and before that worked with Motorola India. I completed all my education Bachelor's, Master's and Ph.D. degrees from Indian Institute of Science Bangalore. And as the course proceeds, possibly based on the questions you ask, shall get to know, about you, your name and so on. So let us start. First, let us look at the plan of the course.

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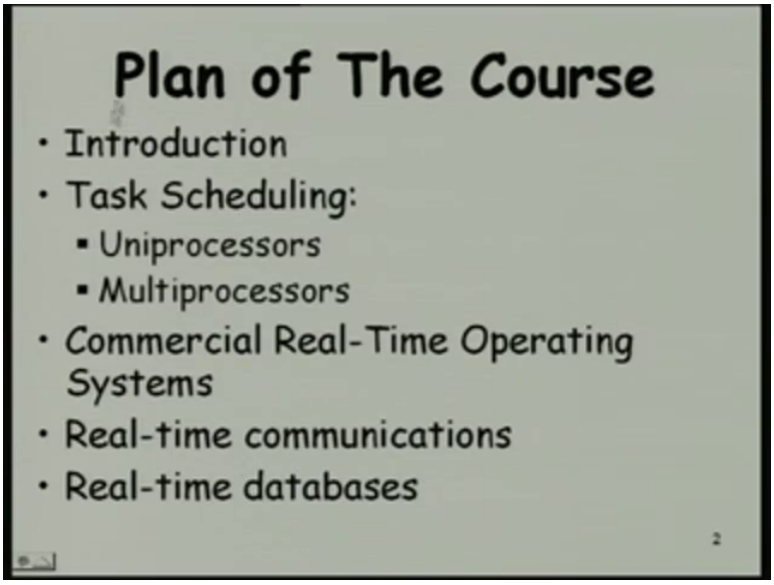

We will have maximum up to three lectures on the introduction and then we will look at some very basics topics of real-time operating systems- because that is the major emphasis of the course real-time operating systems. And as you will soon see, scheduling of tasks is one of the major issues in many real-time operating systems. We will look at uniprocessors, and how tasks are scheduled on them. There is a quite a bit of theory developed over the years for task scheduling in uniprocessors.

Possibly, you have already done a basic operating system course covering how tasks are scheduled in the traditional operating system. We will see that here, in real time systems it is different. We will observe the difference and we will look at multiprocessor and distributed system. We will look at resource sharing issues and after that, we will look at commercial real-time operating systems-- Some of the operating systems that are actually being used in different organizations. And then, will look at real-time communications, because nowadays, most of the real-time systems communicate with other devices over a network or may be on the Internet.

We will see how real-time communication can be supported and then we will look at real-time databases, because increasingly more and more real-time systems are using databases to store data about their environment and process them in real-time. As you can see from the plan of the course, it mostly deals with software issues. We will restrict the hardware issues to a minimum, those that we cannot really avoid as such, but will restrict that. Otherwise the course will be too large.

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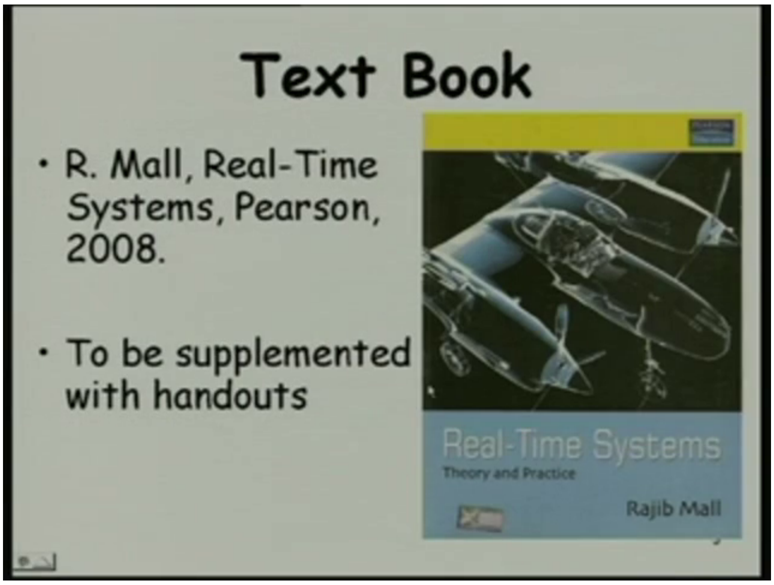

The text book will be the book that I wrote on real-time systems in 2008, Pearson publication and also some supplementary handouts will be given to you periodically.

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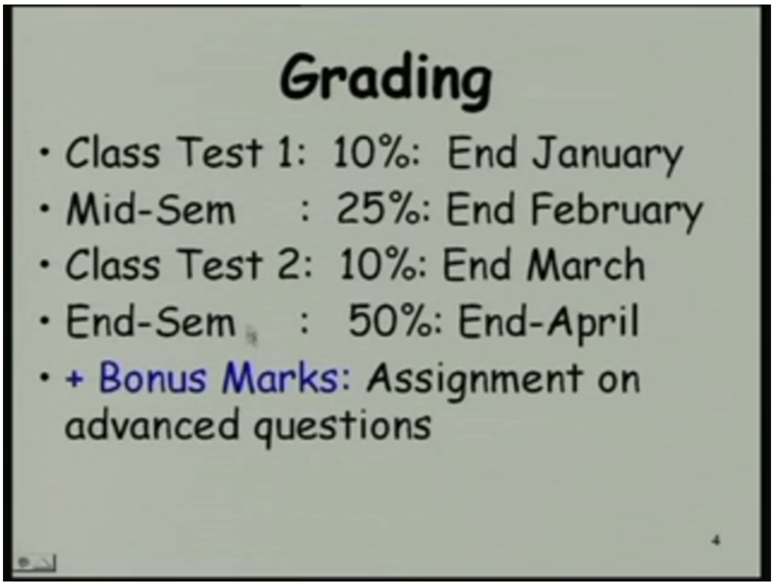

Let us look at the grading issues because in any course grading is important. Class test-1 will have 10% weightage, which will occur in end January, mid semester will have 25% weightage, around end February. Class test-2 will have 10% weightage, in end March and the end semester will have 50% weightage, in the end of April. Almost every month end, we have one test. It is just to keep track whether you are following the course and to know that there is any specific difficulty. It will give you feedback on your performance.

As the course proceeds will pose you some problems, the problems are not there in the book; neither you can easily get them on a Google search. Basically, you have to think to solve them. Those who are able to do those problems will have additional mark more than whatever is displayed here, that will be added to the total more than this 100%.

Based on the 100% and the IT grading scheme like all of us are familiar, 90% or above will get EX-grade etc. will follow that. But one thing is that, the 5% is missing.

We have only 10, 25, 10, 50 is 95% and 5% is not mentioned, 5% is on attendance. Possibly I should have written here, that just to encourage you to attend every class will have 5% weightage given to attendance. If you attend all classes, 5% is assured. Grades are not really an indicator of the intellectual capability; because even the best students can score poorly, because they do not study, or do not attend classes. As long as you are putting effort on this course, keeping track with the lectures, you would be able to get good grades.

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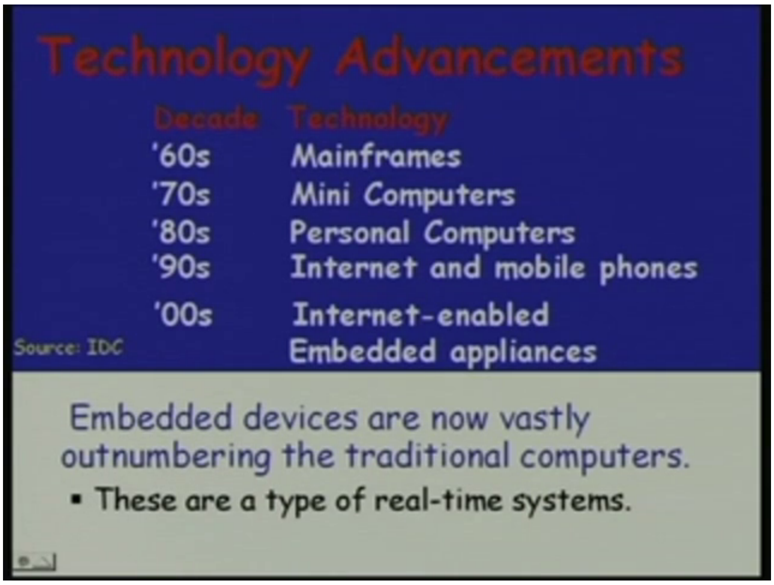

How has the technology advanced over the years? Where are the real-time systems being used? In the 1960's, the computers were basically main frames, and extremely expensive, hardly an organization or an institute could own one. The real-time systems and embedded systems did not exist those days because they were extremely expensive for everyday usage.

In the 1970's, we had mini computers, these were also expensive and in 1980's we had the personal computers. At that time the cost dropped dramatically and therefore the computers got to be used across various domains. This is the period where the embedded and real-time systems usage started to increase. In 1990's, we had the mobile phones and the Internet. This was the revolution in 1990's; everybody started using the Internet and mobile phones.

One thing that is now becoming clear is that, after 2000 embedded devices are vastly out numbering the traditional computers. The number of processors being deployed in embedded devices is about 70% of the total processors manufactured. We now have

Internet enabled embedded devices, where for example, through the Internet we can download code on to the devices.

We will look at several examples of these as we proceed. The embedded devices basically use real-time operating systems. We will now see what are real-time systems, real-time operating systems, and some basic concepts about them.

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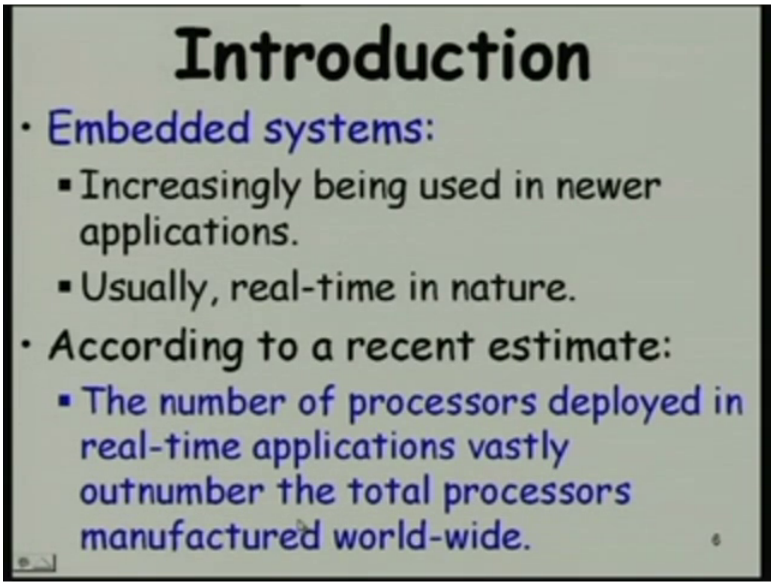

We just saw that the embedded systems are increasingly being used in new applications. These have real-time in nature in the sense that they are based on the premise that some action must take place within certain time limit of an event. The numbers of processors that are manufactured and used in embedded applications worldwide are now vastly outnumber those being used for traditional applications.

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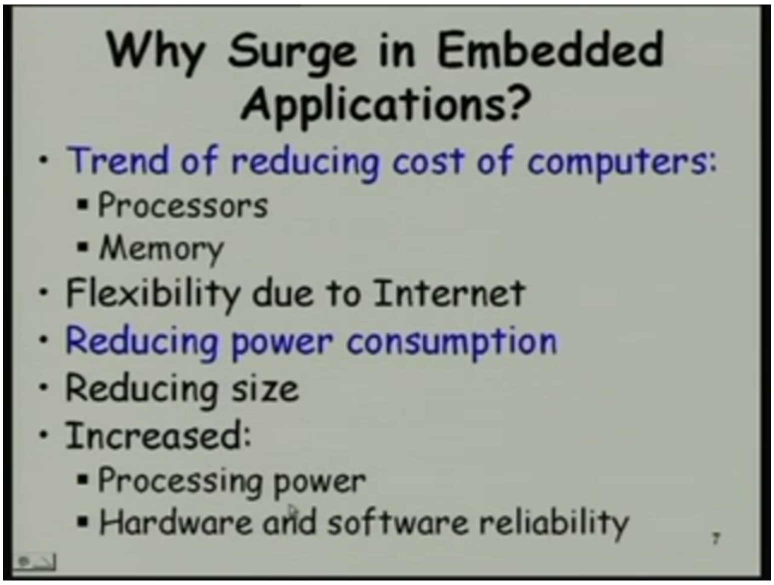

But over the years, why is there a surge in use of embedded applications? There are many reasons which have contributed to this trend of increasing use of embedded applications. One is, the cost of the computers has decreased over the years, from million rupees to few 1000 rupees. While the processor cost has decreased; memory costs have decreased more dramatically. Both semiconductor memory as well as the magnetic memory costs has fallen. In real-time systems actually the magnetic memories are not used that much; instead of that we are using the flash memories. The other reasons for increased use of embedded devices is the flexibility that has come about due to the use the embedded devices, they are small and many in number, but you can easily configure them, and you can maintain them through the Internet.

Another important factor that has helped to increase the embedded applications is the reduced power consumption. Many of these embedded applications, are battery powered and unless they consume less power, they would not be usable. The size has reduced from the size of a room to a very small size. Not only that, we have also increased processing power, and the reliability of both hardware and software have increased over this period of time.

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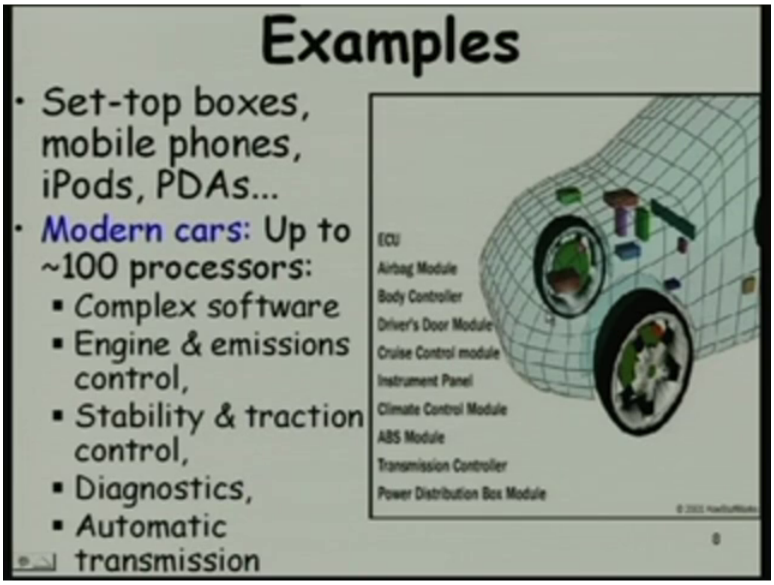

We will see some examples of these applications so that our later discussions will fall into place. So that it will make sense when we say, where to use a time-based scheduling or to use an event based scheduling.

There are a large number of example applications, but we examine only a few examples here, such as, the set-top boxes, mobile phones, iPods, PDA's, etcetera. One example is the modern car. A high-end car can use more than 100 processors which are embedded in various parts of the car and complex software run on these and some of the high-end cars have to programs with code size of up to a million lines.

What do these processors do in an automobile? They do engine and emission control, traction, carrying out some diagnostics and giving early warning of problems, automatic transmission and so on. There are processors at various places in a car, which do various activities. In the present time it is hard to find a car in the road, which does not have embedded processors.

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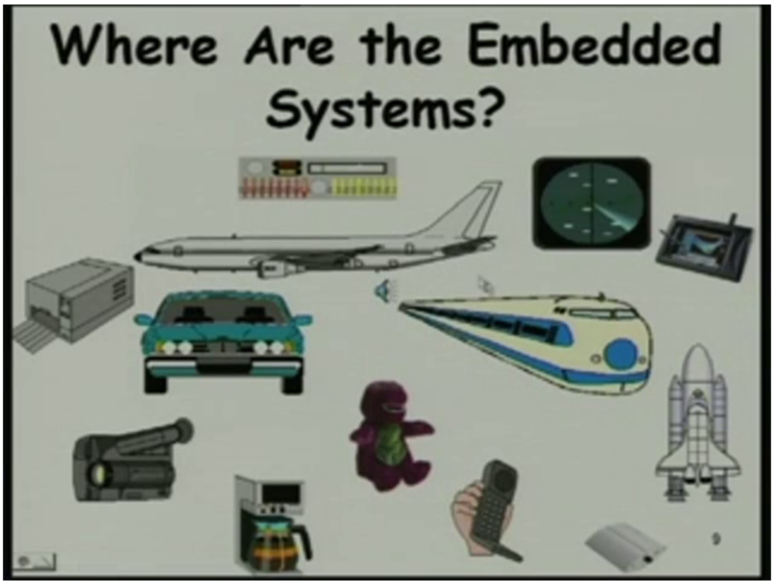

There is large number of embedded systems that are in use in our daily life. But, unless we point out which devices have processors and software real-time operating system, you would not really notice them. For example, laser printer, toys, coffee machine, phone, hand held phone, radar, and Internet router all have embedded processor and programs run on them.

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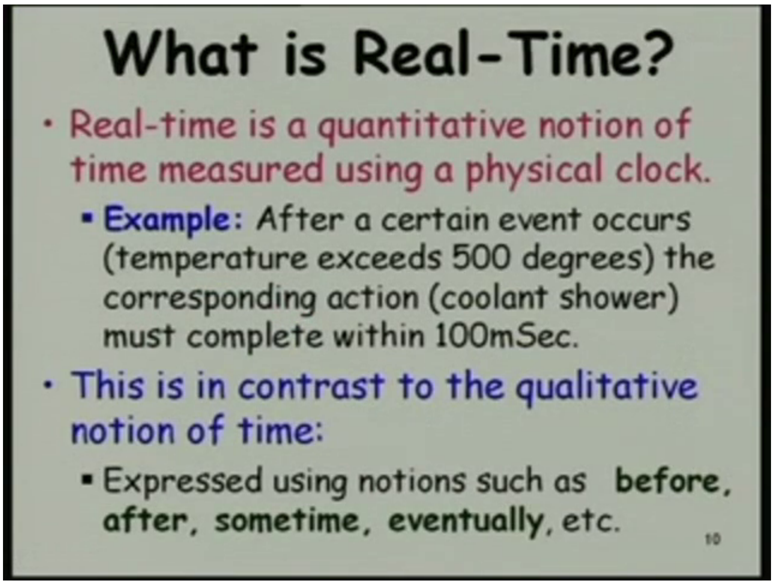

What is real-time and what is a real-time system? A real-time system is one where we quantitatively measure time using a physical clock. In contrast, we have the notion of qualitative time, where we can only say that something occurred before some other thing. Here we do not know precisely how much before or after something occurred. Or we may say something will occur eventually. If you use the terms such as before, after, and eventually, to describe a system, then it will be a non real-time system.

In contrast, if certain event occurs, for example, in a chemical plant, when the temperature exceeds 500-degree centigrade, the corresponding action is that the coolant shower should complete within 100 milliseconds of the temperature exceeding event. Notice, here we have a notion of time measurement using a physical clock, which measures these 100 milliseconds. We will examine more examples and we will also contrast this with a traditional computer.

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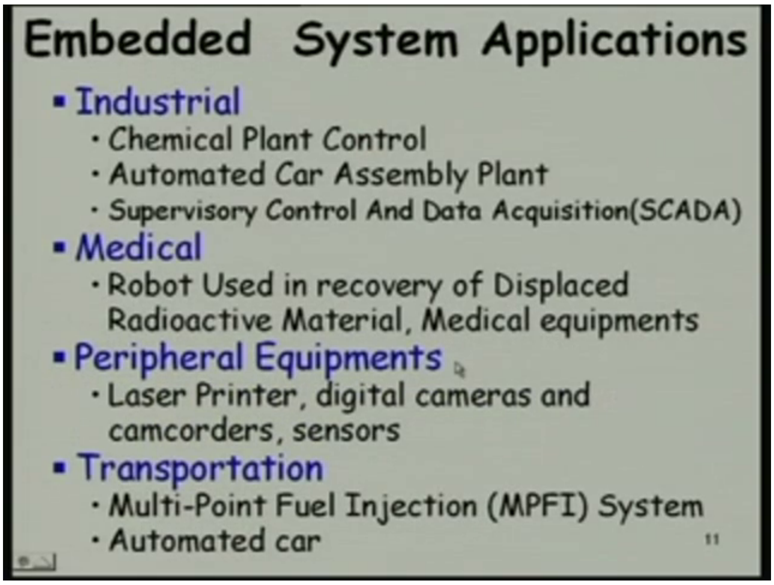

Embedded systems have large number of applications. We will discuss some example applications of each area. We try to find out the kind of tasks they are running and the timing constraints on those tasks.

First, we discuss few industrial applications of embedded systems. Such as:

In a chemical plant control, the rate of chemical reaction depends upon various parameters. Such as chemical concentration, temperature, pressure etc. Based on the changes of these parameters, rate of reaction might vary. So, to control the reaction, embedded systems are used to monitor these parameters for the successful chemical plant operation.

In automated plants, for example in a car assembly plant, most of the activities are automated. When we go to a car assembly plant, we find only a few persons, who are working there. In the plant, there are number of partly completed parts of car moving on a conveyor belt. On the workstations, the workers are doing work on these partly completed parts of the car. There is computer control and synchronization between the various workstations.

Supervisory control and data acquisition (SCADA), this is a very important industrial application, where we can monitor various parameters of a system which are distributed. We can understand this using an example of energy management system. In an energy management system, we have to balance the load sharing, because the consumption by the customers is unpredictable and unless the electrical power is balance the line will trip. So, we have to monitor the power consumption, load shedding and also give this feedback to the generator to keep up with the power generation.

In medical field, most of the medical equipments use processors. Software medical electronics is an important area for real-time systems. Now-a-days, robots are used to do operations with precision and also to do some activities which are difficult by human beings. For example, radioactive treatment. Sometimes the radioactive material gets displaced from the machine, and then robots are used to set the material in its right position.

Different peripheral equipments which are attached to a computer have embedded systems on them. For example, laser printer, we use it every day, but we do not see that there is a processor on it and it does various activities and finally gives resultant in form of a nice printout as output. Similarly, the digital cameras receive the signals, process the signals and store them later in the computer. Camcorders and other various sensors are also having processors on them.

In the transportation, embedded systems are used heavily. Now-a-days, all the cars are road worthy. They use an MPFI system, because it reduces the pollution. The principle idea behind MPFI system is that when a computer controls the exact fuel quantity and the time of injection of the fuel, the car will run at maximum efficiency. At multiple points the fuel is injected, depending on the values of the car speed, acceleration and the other conditions like temperature, etc.

Compared to a carburetor based system, the efficiency of MPFI based system is much higher and this has made the carburetor system obsolete. And then the automated car, where a car is driverless and being driven based on the sensed signals on specific roads. Reports tell that, the automated cars are able to cover distances up to 60 kilometer correctly. Every year a competition for automated cars held and even on crowded streets cars are able to drive perfectly. Possibly in few years we will have this automated cars in our streets as well.

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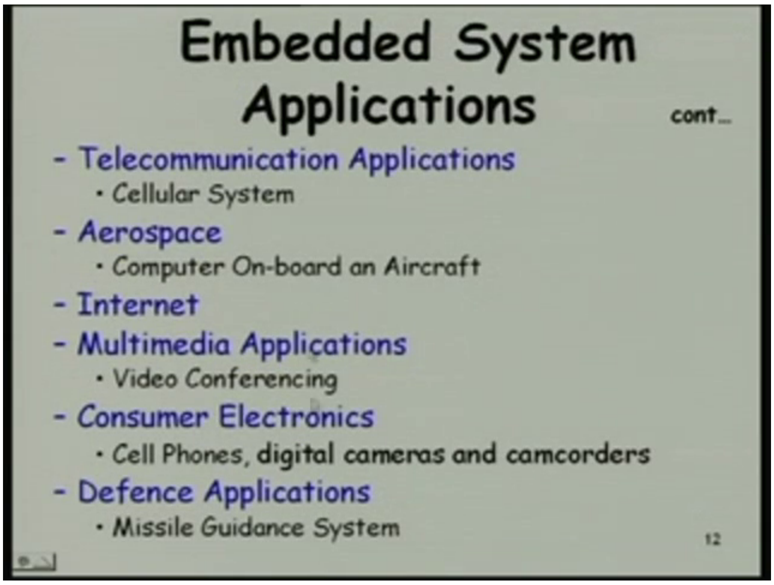

In the telecommunication applications, important example is the cellular system (mobile phones). The base stations receive signal from the mobile phone and give signal to the mobile phone. They use real-time operating systems and handle many tasks at any time. For example, handling SMS messages, call establishment, keeping track of billing, hand off to other base stations etc. The mobile phone itself has a real-time operating system.

Most of the aerospace applications are indispensably have computers on board, because it reduces the botherence of the pilot, and also help them. Sometimes, even without pilot they can fly the aircraft. The internet also uses many embedded systems; for example router.

Multimedia applications, such as video conferencing, it involves handling the signals, compressing, transmitting, receiving it on the other side in real-time. In video conferencing, there is frame to frame translation, so, if the time delay is not proper, it usually results in glitches and we say that video is not working properly, so these are also real-time systems. Consumer electronics items like phones, digital cameras, camcorders are embedded real-time systems. In defense applications, embedded systems are used heavily including the wireless sensor networks.

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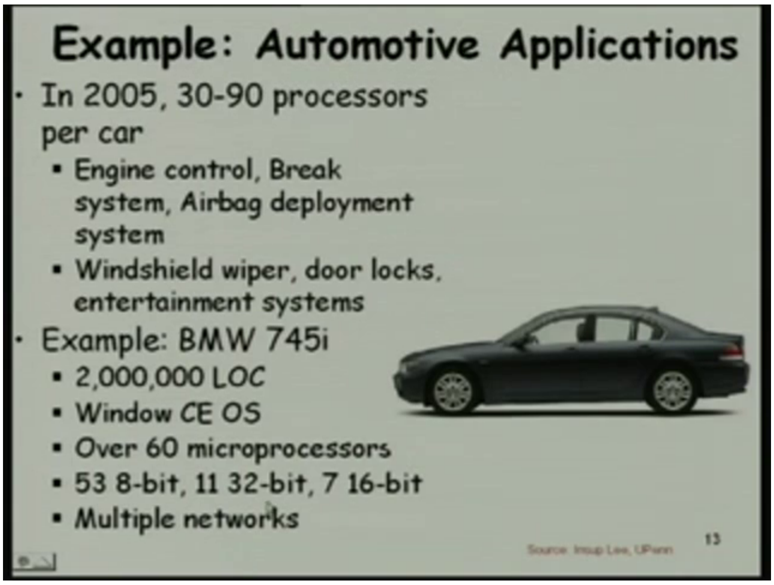

We discuss couple of them in slightly more detail to know the kind of time constraints under which they will have to work and the kind of tasks that are involved. In the automotive application, 30 to 90 processors per car are very common in 2005 and the kind of activities they do is related with engine control (fuel injection), the braking system, airbag deployment, etc. In case there is an accident, within fraction of a second, airbag has to be inflated and it as to be deployed, otherwise it is of no use.

The windshield wiper use processors depending on the rain intensity. They can manage themselves without the driver intervening. The door locks, the entertainment systems, the diagnostics that run on this, for example, measuring the tyre pressure and giving early warning, measuring the health of the other critical parts, etc. These are done by various processors.

One example is a high end car, the BMW 745i, which has 2 million lines of code, uses the windows CE operating system. It has a various types of processors, 53 8-bit processors 11 32-bit processors and 7 16-bit processors and inside the car there are many networks.

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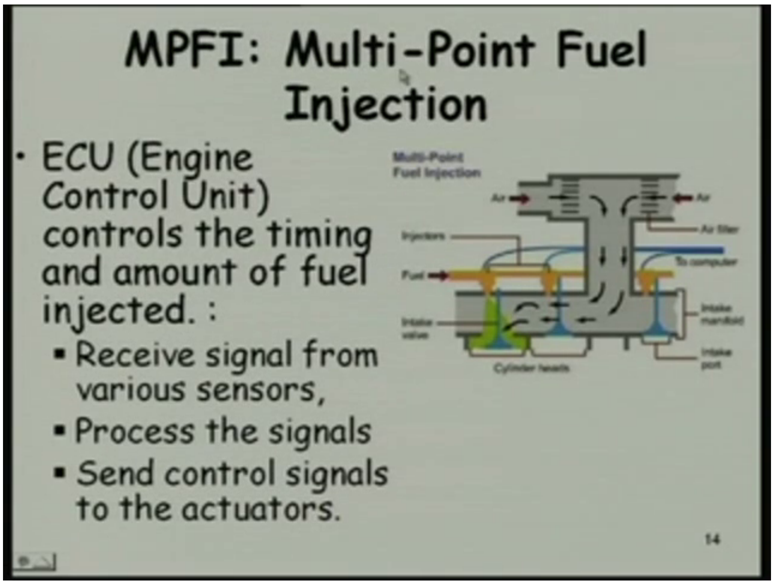

This is another automotive application; almost every car has this, a multipoint fuel injection system. There are different points at which the fuel is getting injected and the quantity of the fuel and the time at which the fuel is to be injected is controlled by the computer. These are determined based on various signals received from different types of sensors; sensors sense the speed rpm (revolutions per minute), temperature, acceleration etc.

Earlier, the mechanical system in a corroborator need to tune the car every once in a while, because that use to go out of a tune and it was inefficient, we cannot really do whatever is done by sampling various events and then taking action based on that and quickly computing how much fuel to be injected and time to be injected and the different places.

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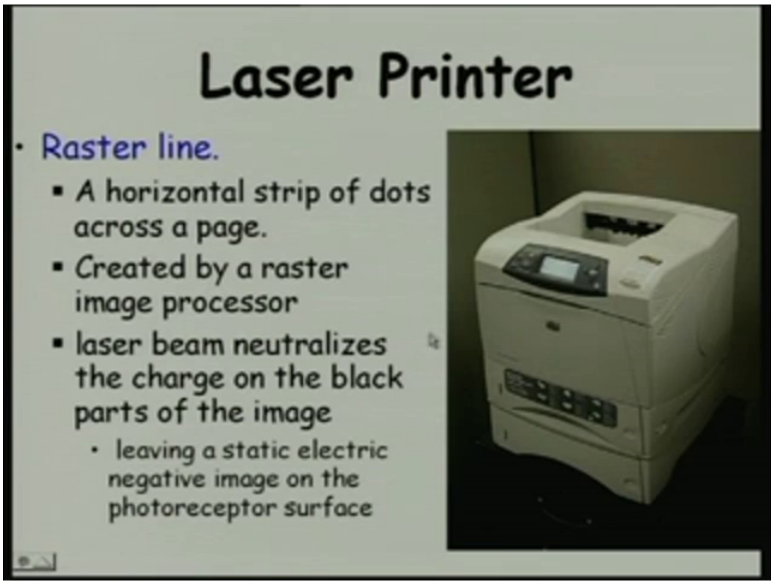

A laser printer, we have used it many times, but there is a processor inside and it does some activities. There is a horizontal strip of dots that needs to be composed. The basic capability is to print a dot or a post script or text file. Each laser printer has a specific language in which the fonts are specified.

Depending on the font that has to be translated to dots and this is done by an image processor and then these are transferred on to a rotating drum inside the laser printer. The image is transferred in the form of charges and a laser beam is used to neutralize charge from the black parts of the image leaving only the static electric negative image on the photoreceptor surface.

When the ink powder is a spread, it gets attached only to the charged parts and then transferred to a paper through electric deposition, because there will be a opposite polarity electric charge which will attract the electricity from the drum and it will get deposited on the paper. The next thing is the fusion where we have this temperature, we observed that when the paper coming out, printed paper is hot because after the ink is deposited, these are fused through heat on to the paper.

Most of these tasks need to be completed in millisecond. For a fuel injection system, milliseconds is the time for different tasks, 10s of milliseconds to 100s of milliseconds.

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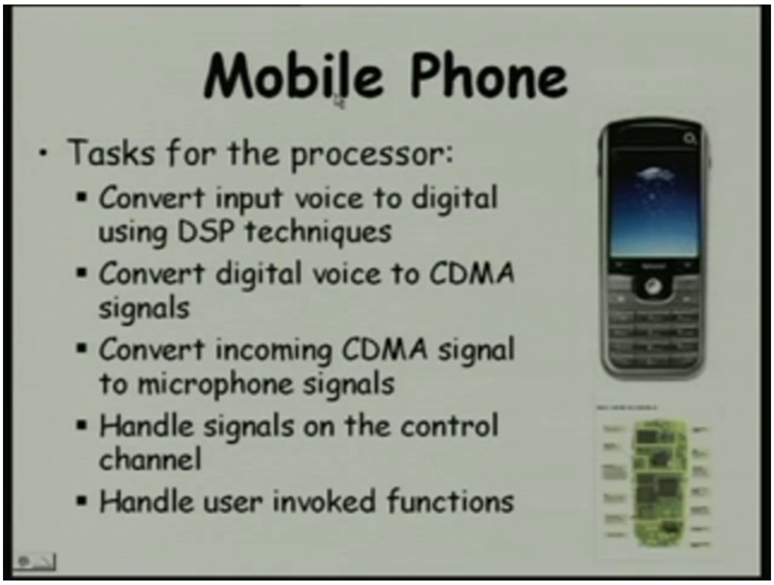

Mobile phone, all of us have used it. Why do we need operating system and processor in mobile phone? To convert the voice to digital using DSP techniques and then to convert the digital voice to signals that can be transmitted. It is CDMA (Code Division Multiple Access) modulated signals and also once the signal comes, these have to be converted to the microphone signals. These are the voice signals but there are also some control signals that are received from the base station.

For example, the base station needs to register the location of mobile phone or when we switch on a mobile phone; there is a transmission on the control channel. Similarly, to send an SMS or to handle user invoked functions, such as to set an alarm or do several of the provided operations on a mobile phone, all these are handled by a processor.

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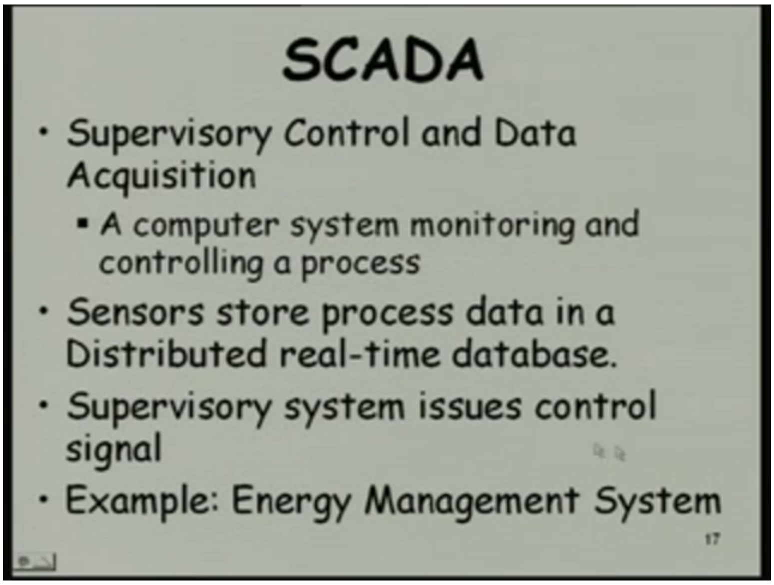

SCADA is an important industrial application stands for Supervisory Control And Data Acquisition. Data arise at various places geographically and these data are collected at different places and even they might be stored at different places by a real-time database. These form a distributed real-time database and then the required information is transmitted to the supervisor and the supervisor can give comments to the different local monitors to take certain corrective actions.

In an energy management system, we are trying to balance the load in electric lines and in a building management system where the timing at which the various lights are switched on and managing the power inside a large building is also a SCADA application.

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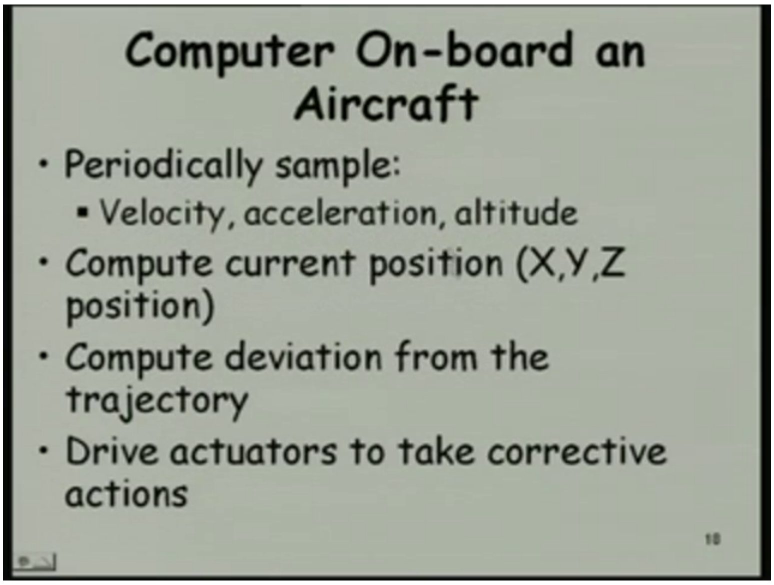

Computer On-board an Aircraft, we are saying that the velocity, acceleration and altitude, these need to be sampled by using sensors and based on these values of velocity, acceleration and altitude, the position of the aircraft and the deviation from the required trajectory is computed. Based on the error in the trajectory, planned trajectory and the current trajectory, some corrective actions need to be taken through the actuators. The tasks will be in the form of milliseconds, the rate at which these are sampled, the rate at which the tasks need to be completed are in the order of milliseconds.

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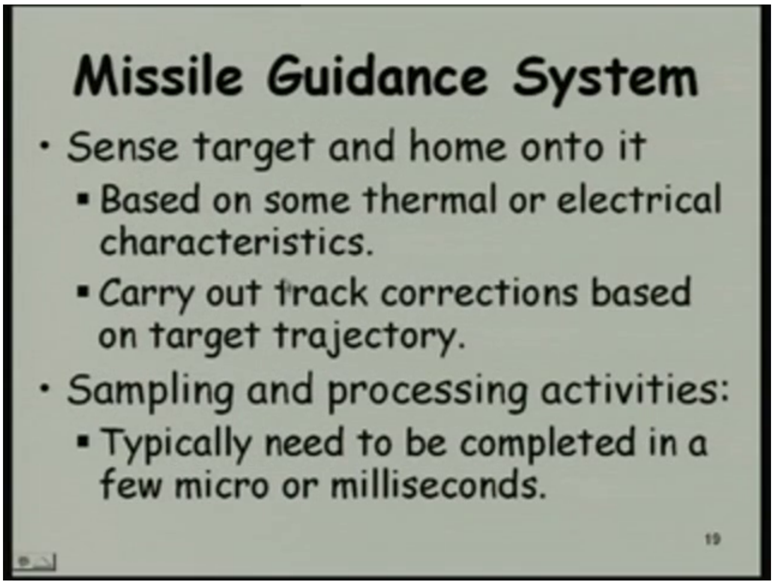

A Missile Guidance System is a defense application, where the system senses a missile from enemy and then sends an antimissile. It just tracks that missile and destroys it. It tracks the missile based on some thermal and electrical characteristics and once it tracks the missile, it computes the trajectory of the track device and then it applies some track corrections to directly meet the enemy missile and destroy it.

The constraints are of the order of micro to few milliseconds, because this travel varies large speeds, the time also needs to be that much smaller and the activities must occur in microseconds.

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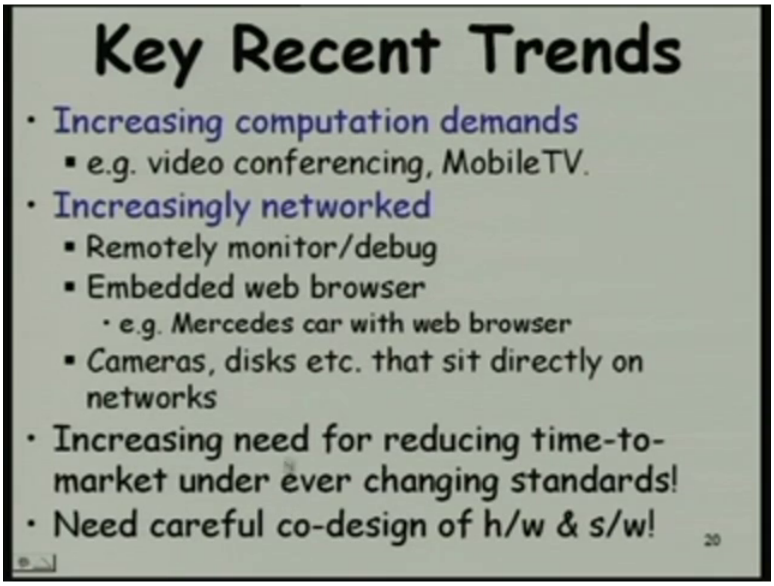

We discuss the key trends in this kind of devices. One is the rapidly increasing computational demand of these devices. For example in video conferencing, we want good quality picture and also voice among multiple participants to be transmitted and heard, which is a very large compute intensive. Because, all these image and data had to be transmitted at a very fast rate to give good quality. Similarly, for the mobile TV (TV on the mobile phone), the processor must be capable of processing the signals and must be able to show it.

One is the increasing computation demands that need more powerful processors, and second is the powerful network connection because most of the devices now are networked, so that we are able to remotely monitor and debug these various devices. We can watch whether these are working in proper condition or failed, and also we can find the reason of their failure. Even the devices have web connectivity, and web browsers, for example, some cars have web browsers.

We have networked cameras and disks. We do not have to plug them to transfer data. They are directly connected with network, and we can easily download and get the data from the computers. We also have a constraint with the commercialization of the real-time operating systems because of the increased competition between different companies.

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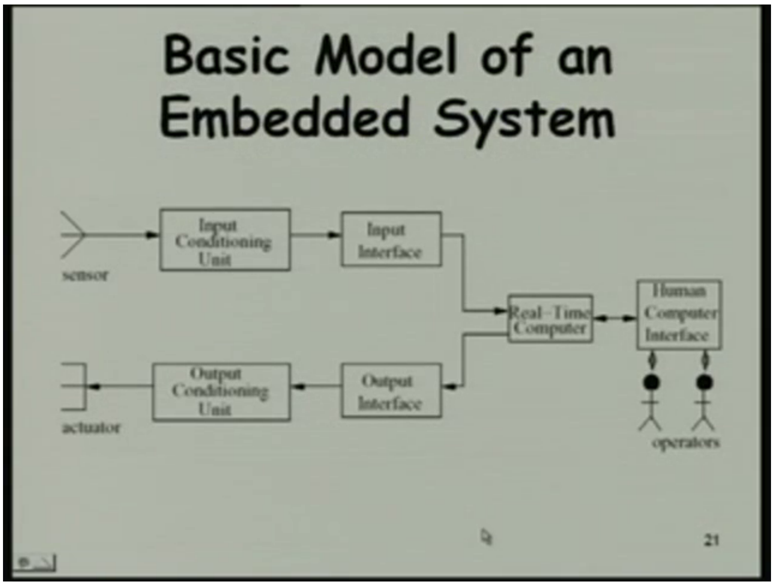

The basic model of an embedded system is shown in the above slide. We said that the embedded systems are a major category of application for real-time operating systems. But, there are also other applications of real-time operating systems other than the embedded systems, for example, large computers also use real-time operating systems. We discuss the basic model of embedded system to make the later discussions more meaningful.

In the embedded system, sensors samples different sets of signals. The signals can be low voltage, low current, direct current, direct voltage or alternating current. So, for the various types of voltage and signals that are to be sampled, we require conditioning unit.

Our computer recognizes voltage and current at certain values, the input interface connects this sampled voltage and current to the computer. The real-time computer processes this signal and there is a human interface where these are monitored and configured. But normally the human interface is not used frequently unlike in a traditional computer. The operator intervenes only if there is an extraordinary situation or to do the initial configuration.

Actions of the computer are carried out by the actuators. These require different amounts of voltage. The current is produced by the computers, so we need conditioning units for voltage scaling, to drive the motor.

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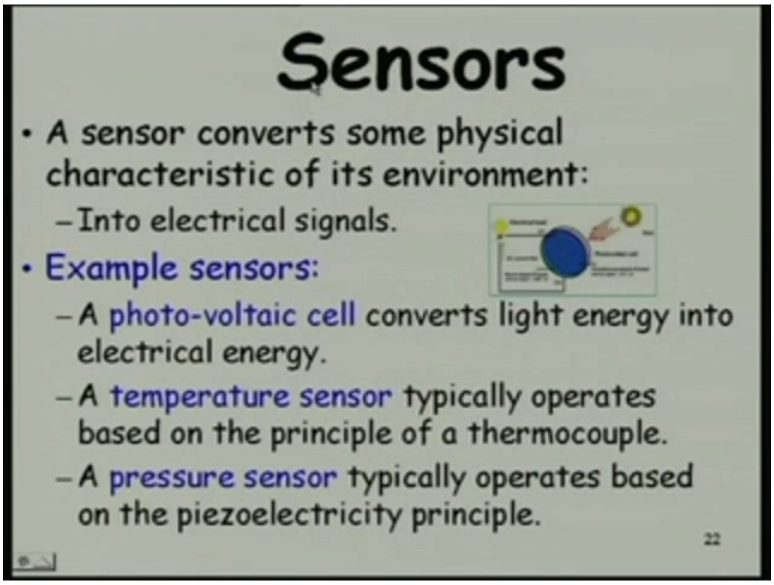

We discuss about the sensors to get the idea about their working. Even though, sensors are not crucial to real-time operating systems by themselves, but unless we have some idea, about kind of signals, voltage levels, etcetera they are taking off, we will not understand the further concepts properly.

Sensors convert physical characteristics into some electrical signals. For example, photovoltaic cell, it converts light energy into electric energy (in terms of millivolts, milliamperes or microamperes). We have temperature sensors, which senses the temperature based on the thermo couple principle. Pressure sensors which operate based on the piezoelectricity principle to generate electric energy (in terms of millivolts).

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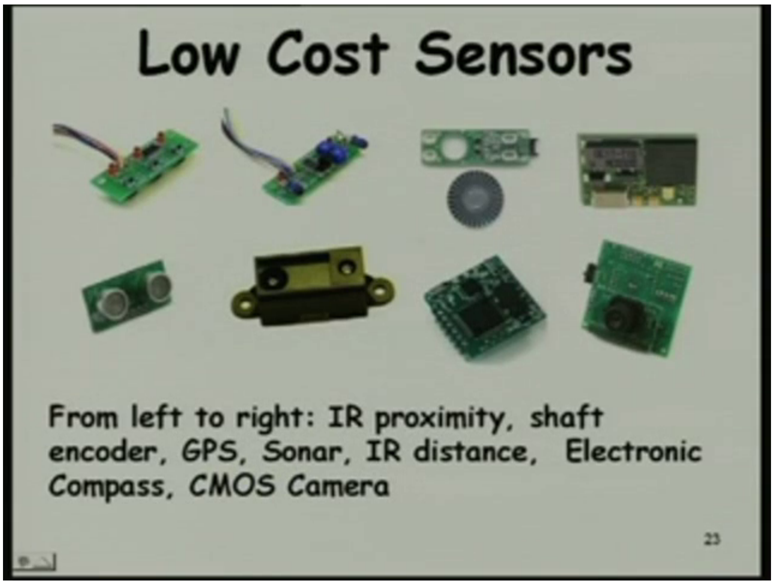

Now-a-days, several low cost sensors that are commercially available. For example: IR proximity server, IR proximity sensor, shaft encoder, GPS, SONAR, infrared distance sensor, electronic compass, CMOS camera. These are various types of sensor that we can buy from the shops and used to build the embedded systems.

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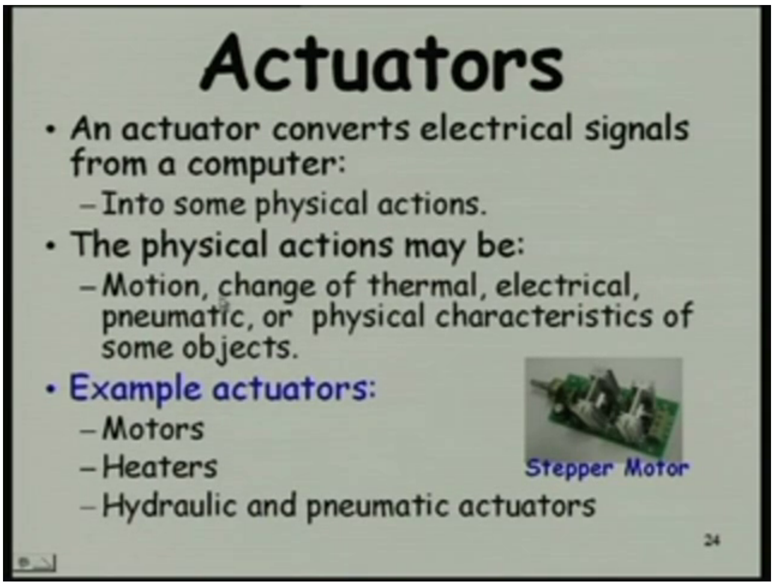

Actuators convert electrical signals from the computer into actions. The actions can be in the form of a motion such as changing the thermal characteristics or electrical characteristics, pressure, physical characteristics, etc.

Examples of actuators are motors, heaters, hydraulic and pneumatic actuators. There is no depth of examples for sensors and actuators, there are many in number. For example, in camera, laser printer or mobile phone, different types of sensors and actuators are needed.

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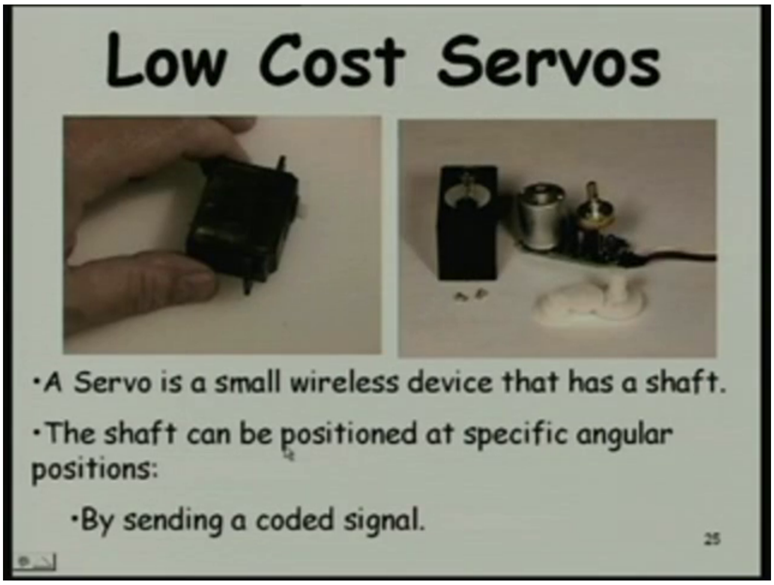

This is low cost servo used in many applications including robots. It is a small wireless device. It has a shaft and can be positioned at any specific angular positions by sending a coded signal. It is very popular in robots.

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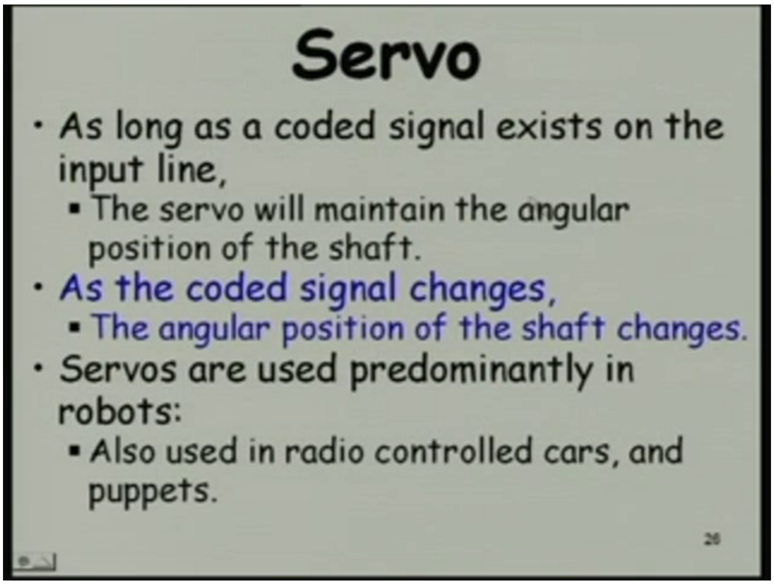

As the signal exists, it maintains the position; otherwise it will change the position. It is also used in controlled cars, and some toys such as puppets.

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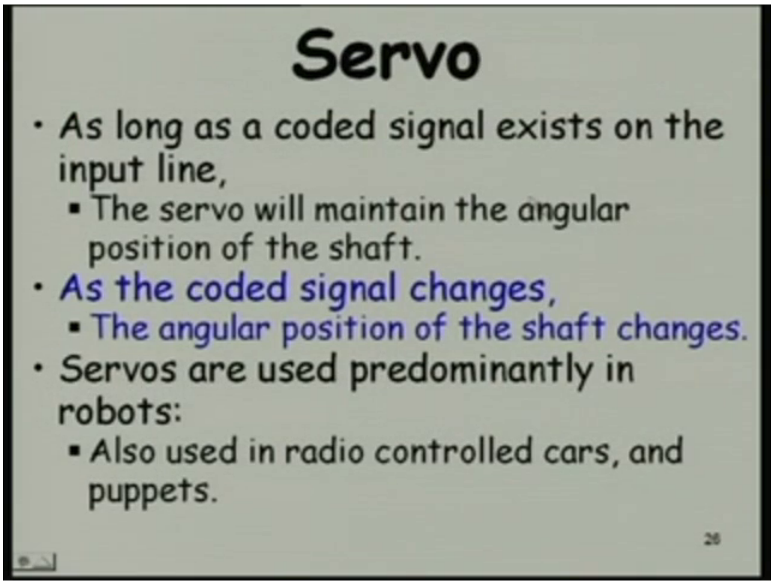
Servo
As long as a coded signal exists on the input line,
The servo will maintain the angular position of the shaft.
As the coded signal changes,
The angular position of the shaft changes.
Servos are used predominantly in robots:
Also used in radio controlled cars, and puppets.

We will discuss about the signal conditioning, even though it is not really a crucial part of the course, but just to have the idea about what this sensor signals are done before they are processed into computer signals, and what happens to them before these are given to the actuator.

Signals in milli volts are need to be scaled up. So, we need voltage amplification and also sometimes voltage level shifting to shift the level of voltage. For example, the level of the voltage is between 10 to 20, we need to -5 or +5 to the voltage. In that case, we need level shifting. We also require frequency range shifting, filtering, the mode conversion AC to DC, etc.

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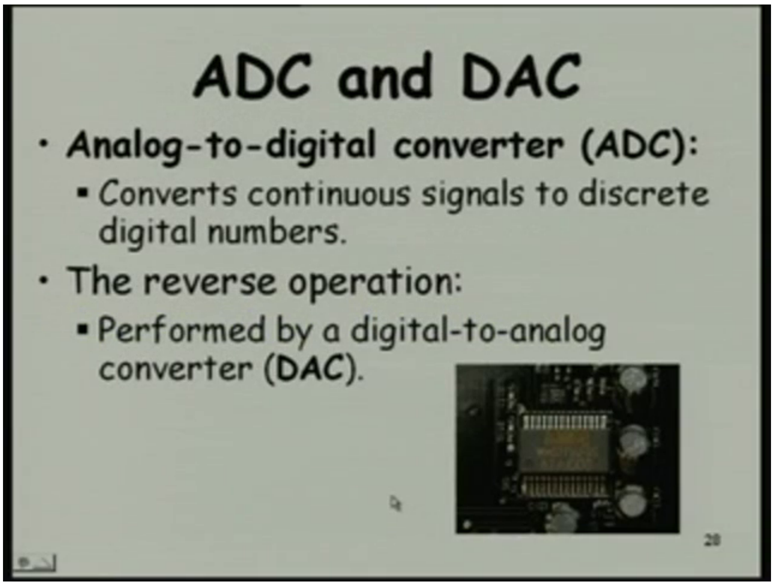

Most of these devices use digital to analog converter, because most of the sensors generate analog signals, whereas our computer needs digital signals. Similarly, the actuators need analog signal, so a digital to analog converter is used.

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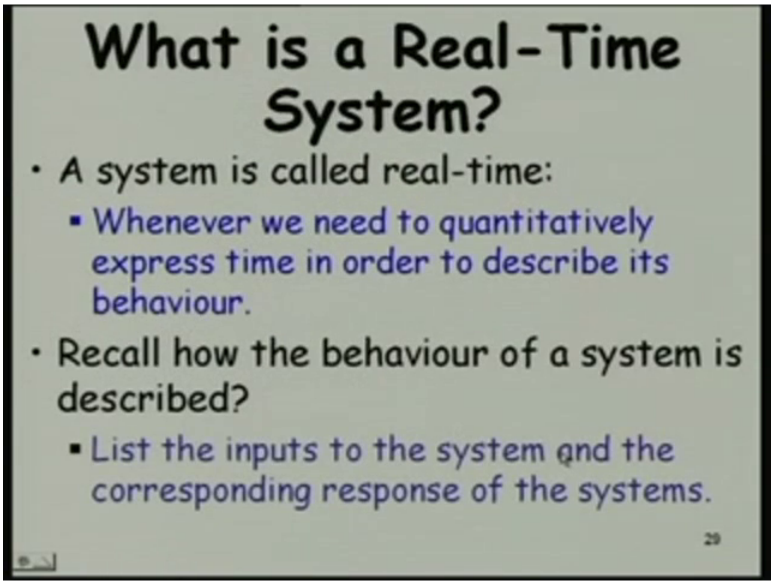

With the basic introduction to the various areas where these real-time devices are used and the basic definition of what is real-time that where the actions need to takes place based on some physical clock, events generated by a clock or the other events generated in the system, we are sufficient information to discuss what is a real-time system. To describe the behavior of a system, if we need to re-set to some real-time description or it implicitly or explicitly use timing aspects, then it is a real-time system.

Most of the real-time systems that will discuss are not all real-time. For example, logging task, it keeps track of different events that occurred or actions that are taken, these occur non real-time, there is no timing constraint, they can completed when they required.

One important issue is the behavior of the system. But what exactly is a behavior and how to describe the behavior of a system. A behavior is the input-output processing, when we give a input, what is the output, and how does that input gets transformed to the output, is exactly the behavior of a system.

To describe the behavior of a system, will have to find what are the inputs, what signals or data was input and what did the system do to generate the output, that is the behavior and to describe that if we need timing, then it is a real-time system.

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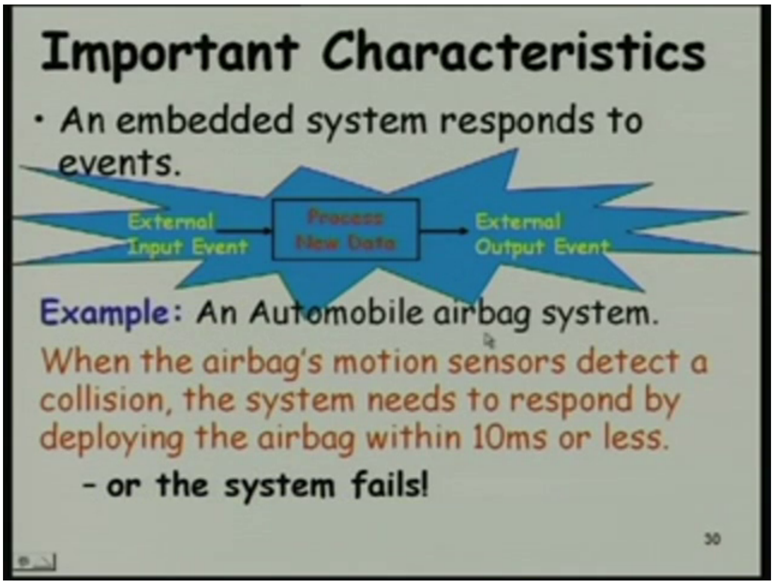

In the next one hour, we will try to find out the characteristics of these systems, because based on these characteristics, we will design our operating system. The operating system facilitates these devices; they must stick to their characteristics otherwise system will fail. One of the important characteristics is timing handling, i.e. responding to event in certain time.

The events are obtained through the sensors and reported to the computer. These are the input event and they need to be processed and some output produced before a certain time expires. For example, a robot senses an obstacle and the robot is progressing, unless it changes its track within the correct time period, it will collide with the obstacle and the system will fail.

Another example is an automobile airbag system, once the sensors detect a collision, the system must respond, i.e. the bag must be inflated, within 10 millisecond or less. Otherwise, it will serve no purpose, because the vehicle is typically in speed and the damage will be done even within a fraction of a second.

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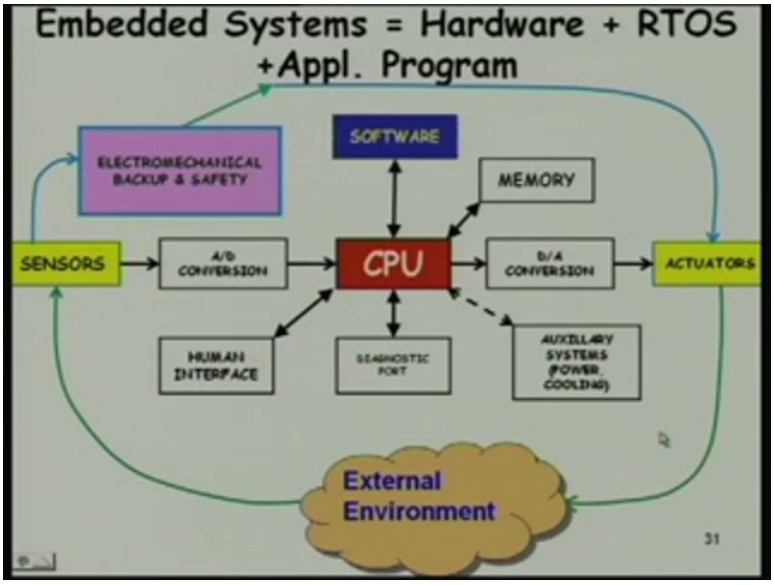

There are some discussion left on the different characteristics and also the basic configuration of an embedded system. We need to have some idea about CPU, memory, sensors, actuators, diagnostics human interface, etcetera. So that we will be able to appreciate our real-time operating systems. We will continue from this diagram in the next class, will stop here.