Computer Integrated Manufacturing
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Lecture 36
Computer Aided Quality Control
(Part 2 of 2)

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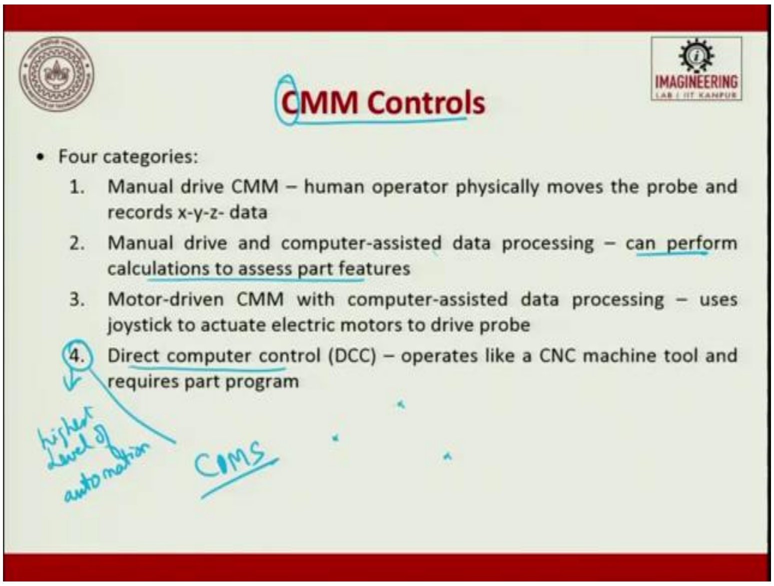

So, welcome to the next topic which is CMM control, in the CMM controls there are four different types of controls. One is manual driven CMM, human operates physically moves the probe and records x, y, z data, for example, in that gear example, he will move to various points touch the points and then record the data.

The next one is manual driven and the computer-assisted data processing you have manually moved it to three places. The computer is used to record the data and generate the feature or generate a result, can perform calculations to assist the part features. For example, flatness, roundness, cylindricity, even then you can have perpendicularity all these things can be measured.

Motor-driven CMM with the computer-assisted data processing uses joystick to actuate electric motor to drive probes. We will have a pendant you will have a drive sticks so, you can do it last one is going to be DCC which directly takes the program from a computer and then use it to a CMM. Try to get the data, try to generate the calibration chart, try to generate the error plot, and then show it. So, this is the highest level of automation and this is what is more prominently used in a CIMS environment because, we have to get the same path what is drawn in the CAD for inspection also, it has to go, it has to go for machining after the machining is over so, this is what was expected to made and what got made has to be inspected by a CMM.

So, this will be done so, now you see computer plays a very important role if computer would have not been there, these two talking cannot happen.

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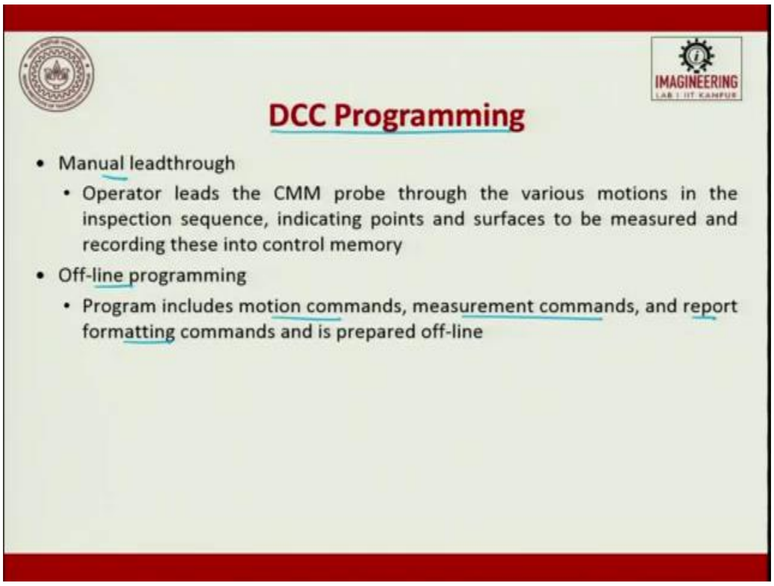

So, DCC programming, DCC programming again you can have manual lead through, operator leads the CMM program through a various motion in the inspection sequence indicating points and surfaces to be measured and recording these into a control memory. So, the same thing what we had in robotics we are also having it here, a manual lead through.

The second one is offline programming the program includes motion control, measurement commands, and the report formatting commands which is then offline from the data which is getting generated or you generate a program and then you push it inside between the free time or doing the dwell time.

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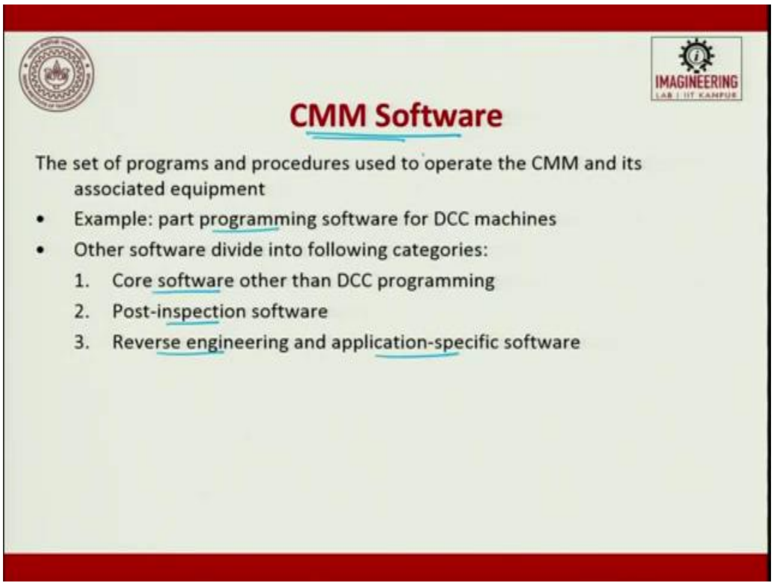

The CMM software's there are several software's which are attached some of them are open-source, some of them are attached and it is fixed to the machine alone. So, CMM software's set of programs and procedures used to operate the CMM and its associated equipment example, part programming software for DCC machines are available today. The other software divided into the following categories. Core software other than DCC post-inspection software, reverse engineering, and application software are available today which are used in CMM for measurements.

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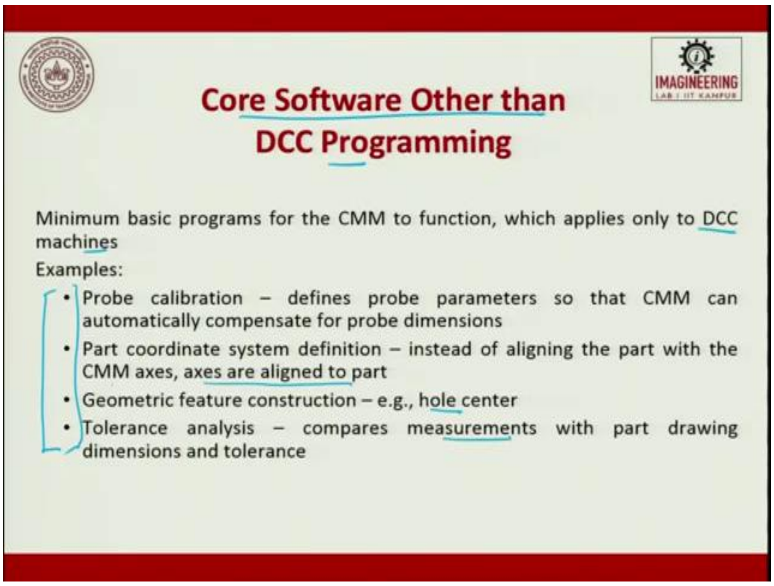

The core software other than DCC programming here, minimum basic program for the CMM to function which applies only to DCC machines. What are DCC machines? Let us go back and see what is a DCC, DCC is nothing but a direct computer control machines.

So, here we use minimum basic programs for the CMM to function which applies only to DCC machines. So, the examples are probe calibration, part coordinate system definition then geometric feature construction and, tolerance analysis these are the four important things which is generally done using the software.

Probe calibration because, probe calibration like you might have varying height where there is a wear and tear where there is a fitting, spring losing its repeatability so, we always do a probe calibration which defines probe parameters so that the CMM can automatically compensate for the dimensions part coordinate system is instead of aligning the part with the CMM axis, the axis are aligned to the part.

Just like your wall coordinate system, user coordinate system we, converted as a local with respect to the part what is the alignment to be done. So, then geometric futures, for example, whole centers and tolerance analysis compares measurement with the part drawing dimensions and tolerances.

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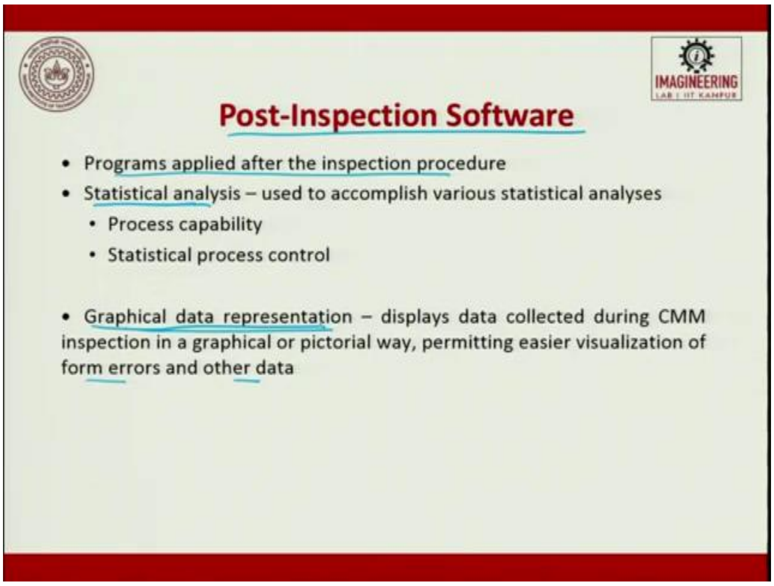

Post-inspection software, so the programs applied after the inspection so, you have done the measurement now, you have to get the deviation chart so, that is called as programs applied for after the inspection procedure, so we try to look at statistical analysis like process capability and statistical process control. This can be done or it can be graphical data representation that's what I say deviation, displace the data collection during CMM inspection in a graphical or a pictorial way permitting easier visualization of form errors and the other data.

So, post-inspection software does a statistical analysis and graphical data representation. This is on top of your software cost.

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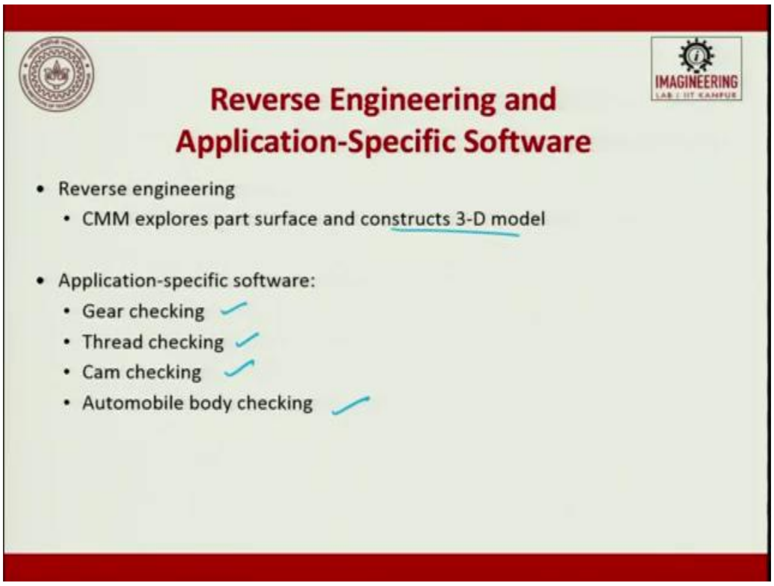

Reverse engineering software's today which part of non-contact measurement reverse engineering and applied software are reverse engineering is CMM explores the part surface and constructs 3D models so, you will have gear check, there are software available so, you have all these things you pull that library function immediately you have to activate certain points then if the checking is done and it will give you the data. So, for gear checking thread checking, cam checking, and automobile body checking is done.

Today there are CMM where a complete car can be parked in the CMM space it inspects and gives you what are all the deviations which are there as per the drawing.

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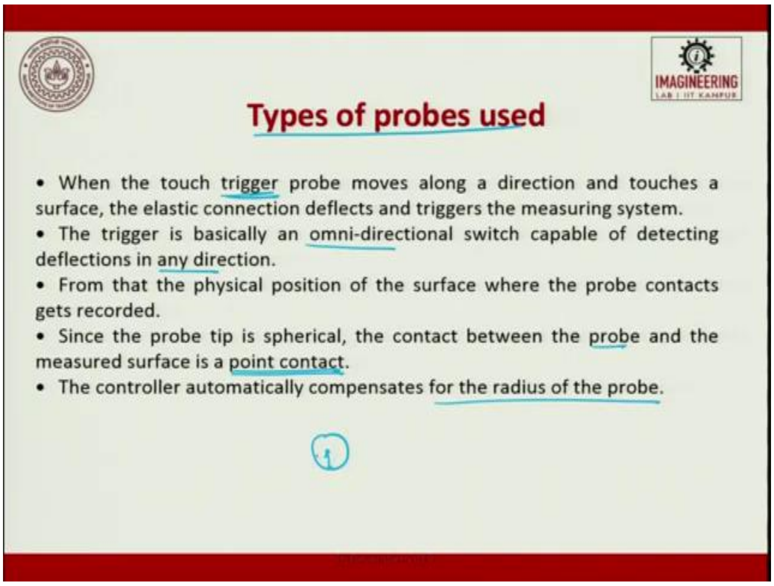

When we look into the last part of the components there, the types of probes so, when the probe touches the part what happens, it tries to trigger, so now the triggering mechanism has to be included in the probing head. So, that is what we will try to see now, when the touch-trigger probe, trigger moves along a direction and touches a surface, an elastic connection deflects and triggers the measurement system.

I touch the surface, and moment I touch the surface, the probe equilibrium position is disturbed now, the disturbed position is recorded and that becomes your x, y, z coordinates. A trigger is basically an Omni-directional switch capable of deducting deflections in any direction, Omni; multiple any direction.

From that physical position of the surface where the probe contacts gets recorded. So, wherever it touches trigger is done and immediately x, y, z data is done. Since the probe tip is spherical, the contact between the probe and the measured surface is always a point contact is good rather than line contact. The controller automatically compensates for the radius of the probe. Whatever is the radius that does not matter so, it is always done with the probe it is done with the center so, you know the radius so it locks it and give you the distance.

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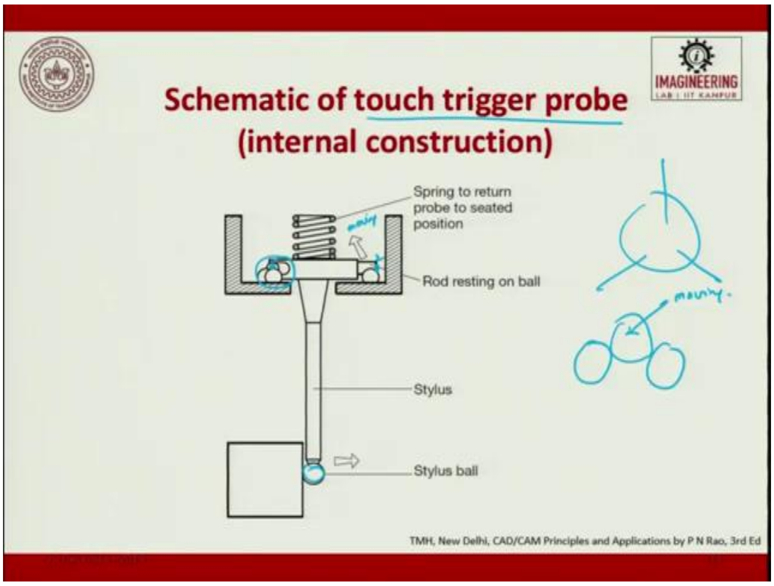

This is what is the internal construction, so you see here, this is the stylus ball, this is the stylus so, this is sitting, resting, it is a three dimensional one. So, it is resting, this is one, here you will have two and the backside you will have three. At 60 degrees each, it is almost this is what is the resting position where this probe is sitting and the spring to return probe to the seated position.

This stiffness is very important this stiffness makes sure that the probe always sits in the position. So, if you look at this portion, you will have two balls, which are attached to the rod resting with it, and then you will have a cylindrical surface which comes from the moving surfaces.

If I talk about this as the moving so, this will disconnect, and moment there is a, disconnect then immediately it records the data, this is the internal construction of the touch-trigger probe. So accordingly for a star type also you will have the same.

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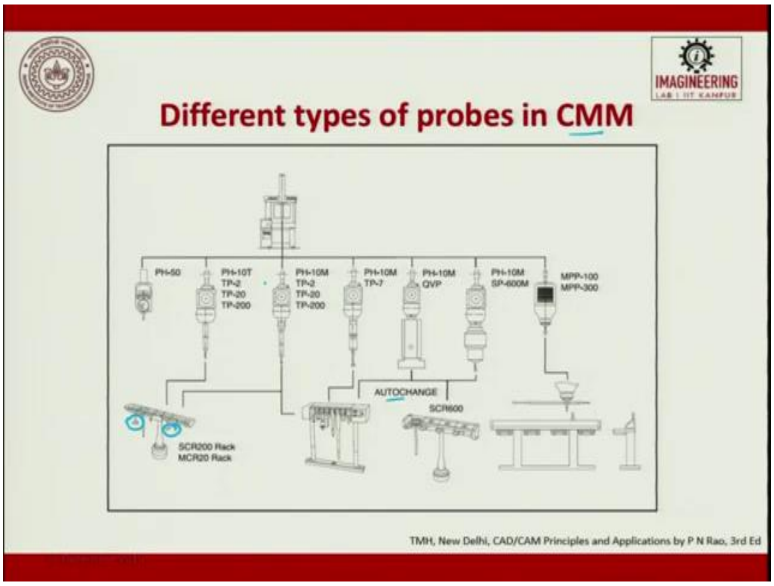

So, different types of probes in CMM a use star it is not only one, these are the different types of probes you will have. So, you can have link there, you can have star type so, you can see a ring-type so, these are multiple probes which are used. Okay, and like in CNC machines here also you can have auto changes where this tells the probes are changed and the head will be the same.

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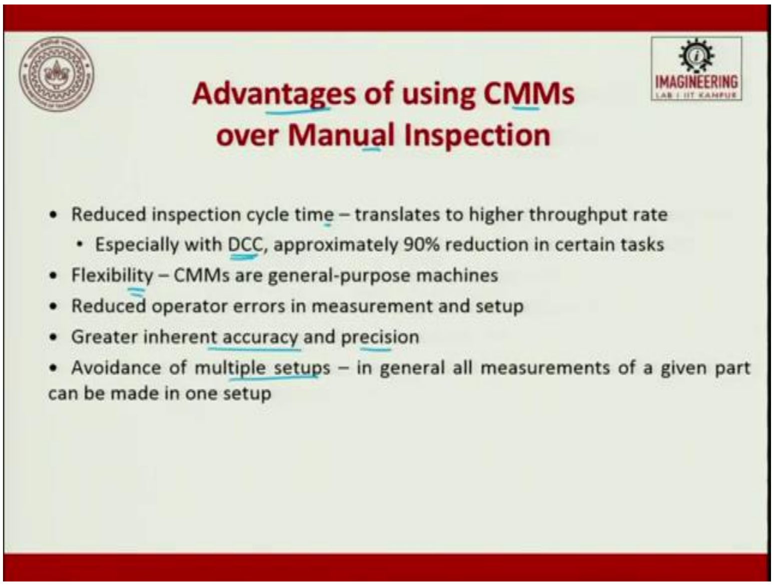

So, what is the advantage of a CMM or a manual inspection it reduces cycle time because it translates the higher throughput rate especially with DCC, you saw what is DCC, approximately 90 percent reduction in the measuring time. It gives you flexibility I do not have to prepare gages every time so, the CMM are a general-purpose machine, it reduces operator error because everything is calibrated with one surface and touch. It gives greater inherent accuracy and precision.

Avoids multiple setups for example, with a single setup you can do, almost all features measurements in one shot. So, it avoids multiple setups.

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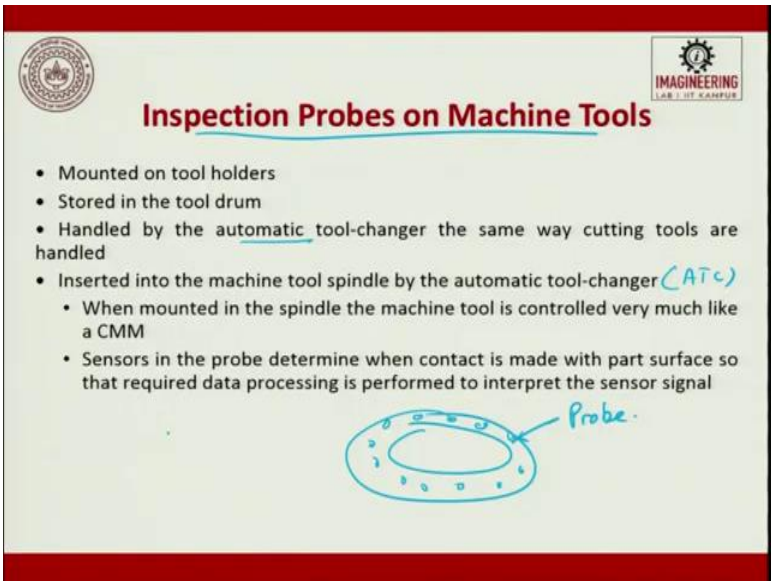

So, the inspection probe on machine tools so, today what is happening rather than having a CMM separately the machine tool, in the machine itself they are trying to interface a inspection probe. With it is mounted on the tool holder it is stored in the tool drum, the probe stored in the tool drum, in the magazine handled by the automatic tool changer the same way a cutting tool is handled we have a probe, so we saw a magazine, tool magazine in a CNC machine so, in this, you will have multiple tools so, you will have one tool as also your probe.

So, handled by automatic tool changer from switching from the cutting tool to a probe we will use ATC to change. Inserts into the machine tool spindle by the automatic tool changer ATC, and then it mounts. So, when mounted in the spindled machine tool is controlled very much like a CMM. The sensors in the probe determines when contact is made, with the part surface so, that the accurate data is getting processed using the system.

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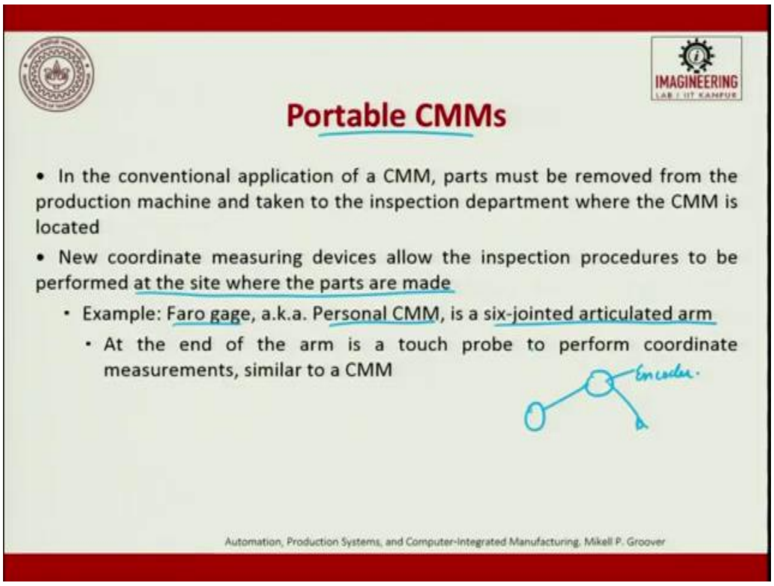

There are also today portable CMMs in the conventional application of CMM, part must be removed after the production machine and taken to the inspection department where the CMM is located. New coordinate machines allows the inspection procedure to be performed at the side where the parts are made. Suppose, you have a large one, large component which is to be made so, we will try to talk about this example, faro arm is an example wherein which it has a personal CMM it has 6 joints articulated arm just like a robot. And it can do the measurement.

So, it is almost like a robot arm so, you will have rotating joints you will have several rotating joints and each joint you will have an encoder and that encoder measures the x, y, z and communicate. At the end of the arm is a touch probe to perform the coordinate measuring action.

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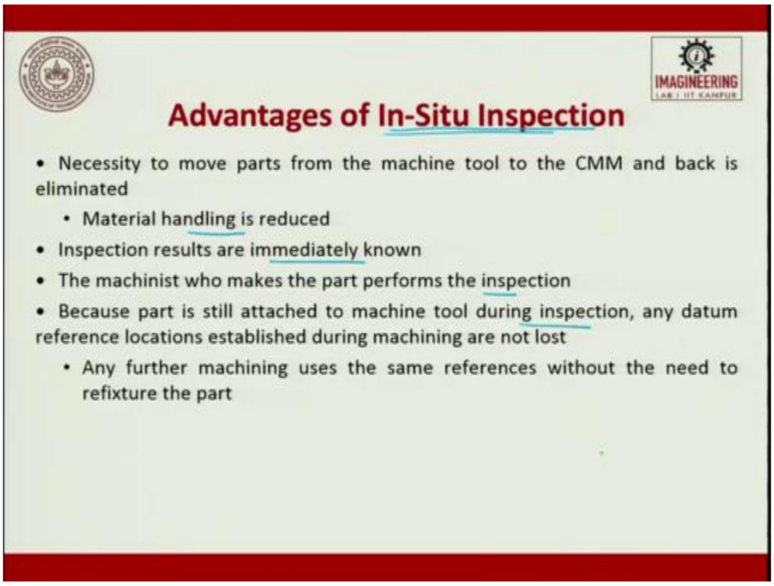

The advantages of in-situ inspection and the necessity to move parts from the machine tool to the CMM and the back is eliminated so, we use in-situ inspection this is what I said. Earlier we use to check the quality after the part is made, nowadays it is checked while the part is made between to the operations it checks and measures whether the dimensions are okay for the next tool to interact. So, the material handling time is reduced, the location every time location and relocating the workpiece is reduced so, In-Situ inspection is giving a big advantage in reducing the time and also giving accurate data.

Inspection results are immediately known, machinist who makes the part performs the inspection so, he is aware of what is what and the part still attached to the machine tool during inspection.

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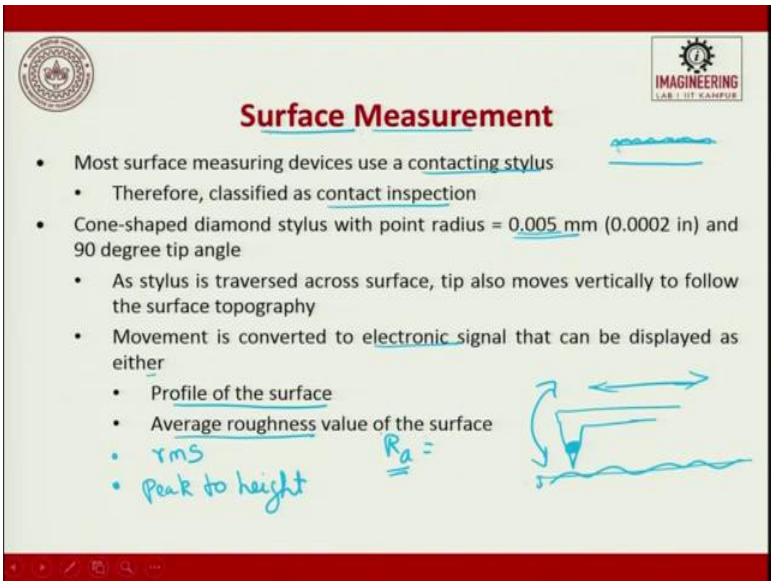

So, the next measurement technique is going to be using surface. So, till now we were only worried about dimensional form accuracies now, we have to also talk about the surface. The surface measurement is very important the surface measurement is important because it is going to have a direct influence on the component life.

If the surface is undulated, there are lot of sharp edges, so these sharp edges can be fatigue when we do a fatigue cycle these can be stress concentration points the components can felt or when you have a sharp edge when the water gets deposited, the OH gets deposited it can start corrosion from there.

So, it is always advisable to have a flat surface as compared to that of a surface where it is rough for certain applications. So here we would also like measure the surface. When we want to measure the surface, we have to take a continuous contact data. So, we are talking about in shaft lower level, when we talk about STM scanning, tunneling, microscope again it is noncontact very small, but you have to take the data all across the surface.

Whereas in CMM generally what we use to do is, we use to take lot of point data. And this point low will be converted into surfaces. So that is a difference between CMM data and the surface data. In the latest advancement CMM also have started taking continuous data so, today CMMs machines whatever comes into the market can also be used for surface measurements. So, most surface measuring devices uses a contacting stylus. Therefore, they are classified inter contact inspection. So, here also what happens is when you try to contact, you will try to have a probe and in that probe, in the bottom portion, we will try to have a stylus ball. So, that is what a cone-shaped diamond stylus with a point radius of 0.005 millimeter and 90 degrees steep angle is used. You can use it like this, or you can also have a ball which is attached so, you will have a point contact.

As stylus is traversing across the surface, tip also moves vertically when it is scribed over the surface the tip also moves up and down. Vertically to follow the surface topology, the movement is converted when you try to drag when this up and down movement is there. This movement in turn will be converted into an electrical signal you use a Wheatstone Bridge principle and then this up and down movement whatever was there is converted into electronic signal that can be displaced either as a profile of a surface or it tries to calculate the average surface roughness.

So, if you are working on electrical field we also look at RMS values or we try to look at peak to valley height. These are some of the parameters which are used to measure the surface. So, once we have a lot of data so, then what we do is, we try to figure out the average roughness, top, and bottom, and we try to make the uniform distribution of top and bottom, so there is a shift in the central line. So how much is the shift will be reported as average roughness.

And interesting thing we should understand, whatever roughness value Ra you get, you can have two different signatures but, it can give you a same data. So, people always are giving that measuring roughness in which not the only right parameter for the surface. They look for other combinations.

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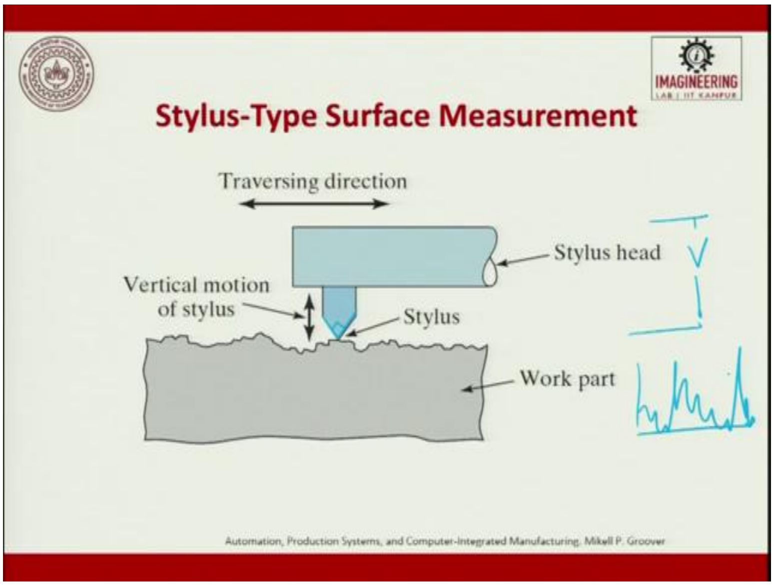

So this is the traversing direction I told you this is the stylus where in which it is diamond and it is 90 degrees. You can have this or you can also have a circular one where you get a point contact. A circular one is more preferred now days because; this tip also gets worn and torn. So, why I said when the traverse direction moves the stylus tries to move on the surface so, when it tries to move on the surface there is a vertical motion which I said up and down.

So, now this, in turn, is communicated to the stylus head, the stylus head, in turn, gets attached to a Wheatstone Bridge principle and that tries to give you output in terms of voltage. So, you will try to get a plot in terms of voltage versus time or voltage versus distance. So, then this data is further processed through a software or through electronic hardware and then you try to get the Ra values.

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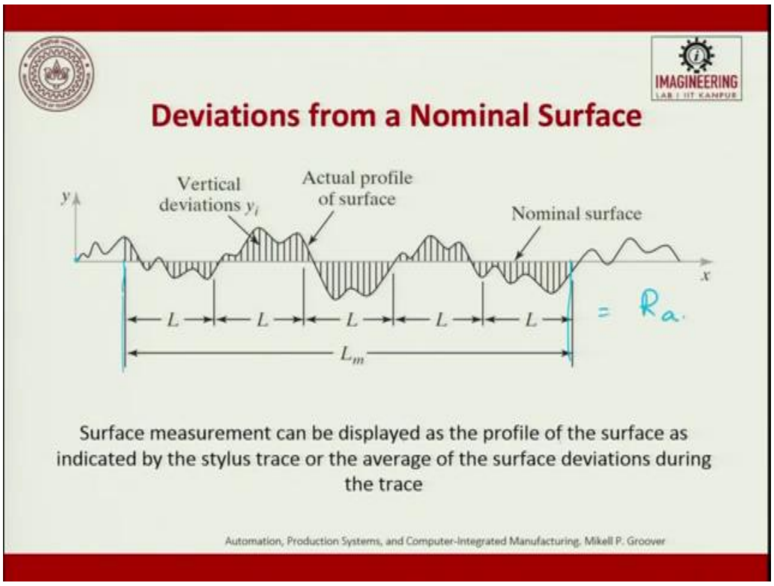

So, this is how a typical Ra value is calculated the stylus is cribbed over a surface so, you will have several undulations which are getting formed and these undulations will be divided into several small segments and what they do is they try to find out the area above the line and the area below the line is uniform. So, this is the place where the stylus starts scribing, and then from here onwards we start the measuring distance so, this is the measuring sample length this will be divided into several fragments and in each fragment, we try to calculate the area above and below the curve.

Then we try to take the average across all these Ls and then we try to get the average value so, this is the actual surface which is undulated, these are the vertical deviations in the y-axis and this is the nominal surface which is there. Surface measurement can be displayed as a profile of the surface as indicated by the stylus trace or the average value of the surface deviation during the trace, so this leads to a Ra value.

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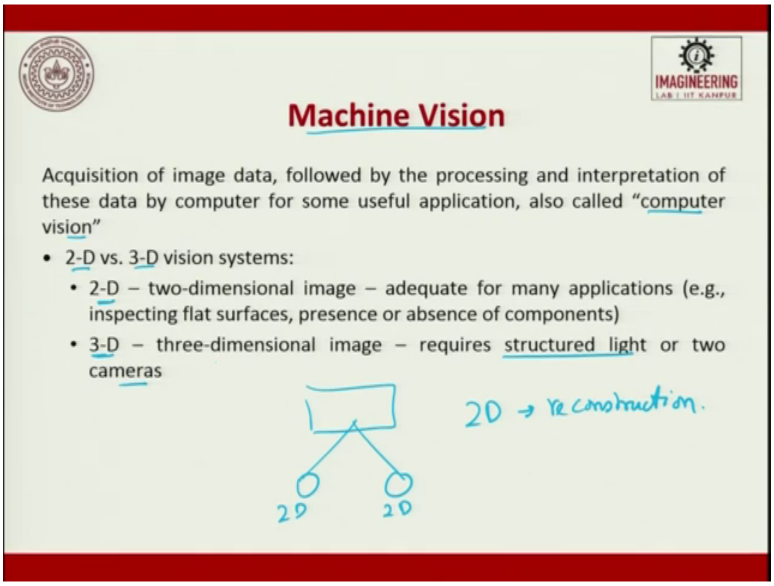

So, the next part, we saw contact type stylus and we saw also, CMM, next we will go into machine vision. Machine vision is under non-contact type. Acquisition of image data followed by the processing and interpretation of these data by computer for some useful application is also called computer vision. So, there are 2D and there are 3D vision systems, 2D vision systems adequate for many applications, for example inspection of a flat surface. Presence or absence of a component we use 2D vision system, but now a days 3D vision systems, have also come into existence where in which it requires structure light or two cameras to measure a three-dimensional image.

So, you will have an object you will have two cameras so, these two cameras will try to give you, you images this will give you 2D image, 2D image when we try to reconstruct these 2D, 2D images we try to get a 3D image from the 3D image we try to give the interpretations. So, machine vision you can have 2D image, a 2D vision system, and 3D vision system.

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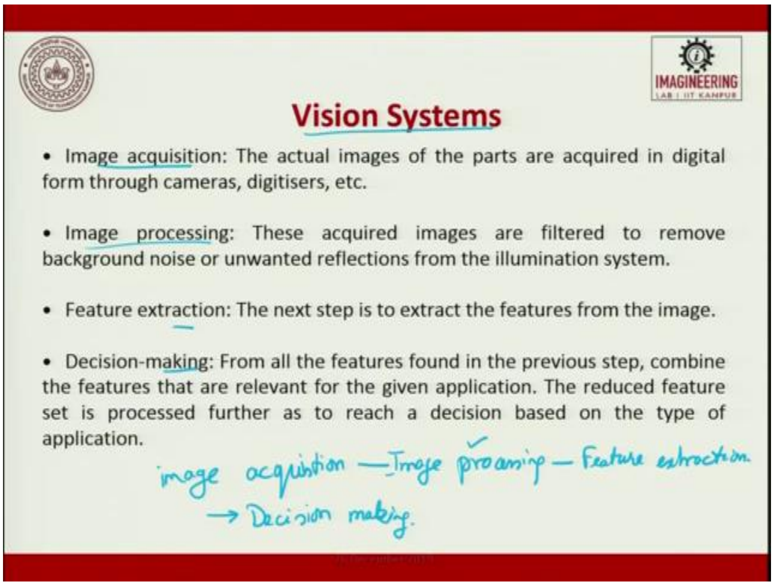

So, when we talk about the vision system these are all the four steps which are there, first is image acquisition, the image acquisition is the first part. So you will use a camera to acquire the real-time data whatever it is. The actual images of the part are acquired in digital through a camera or digitizer etc. Next, the acquired image has to be processed so, image processing happens there. These acquired images are filtered to remove background noise or unwanted reflections from the illumination system.

So, you will have a light which is thrown because a camera which is taken in dark you cannot get the image. So that is why even your normal camera what happens when you try to press an image and if it has a night eye application, it will first flash throw the flash and then it will try to open the shutter and close the shutter. So, the light what is thrown is trying to illuminate the object.

When the illumination happens, you will have the basic image as well as the background. Illumination effect which is given by the light. So, during image processing, we have to nullify those things and acquire the image. So, that is what happens in image processing. So, image acquisition is the first step then we try to do image processing which is the second step then we will try to move to feature extraction three, and then what we do is, we try to take the decision making.

Image processing is the second step and feature extraction, feature extraction is the next step, from the in-processed image the features will be extracted. The next step is to extract the feature from the image. First, you have only removed the background noise you have done some corrections in the image. Then, from that image whatever you have acquired now, you have to extract features, so that these features can be used for some output.

Then from the extracted feature, you try to take decisions whether this information is correct or wrong or what is the more information it is giving. From all the features found in the previous step combine the features that are relevant for the given application. The reduced feature said is processed further as to reach a decision based on the type of application. Vision-based system is today playing a very very important role. So, when we are talking about reverse engineering non-contact type today there are lot of systems wherein which it works on imaging techniques.

Acquisition of image which depends on the camera. Suppose if the camera is of not a high quality, rest all softwares are a very good quality does not suffice any use. So the hardware has to be compactable with the software. The software first you do processing then you do feature extraction and last one you do, decision making on the extracted feature.

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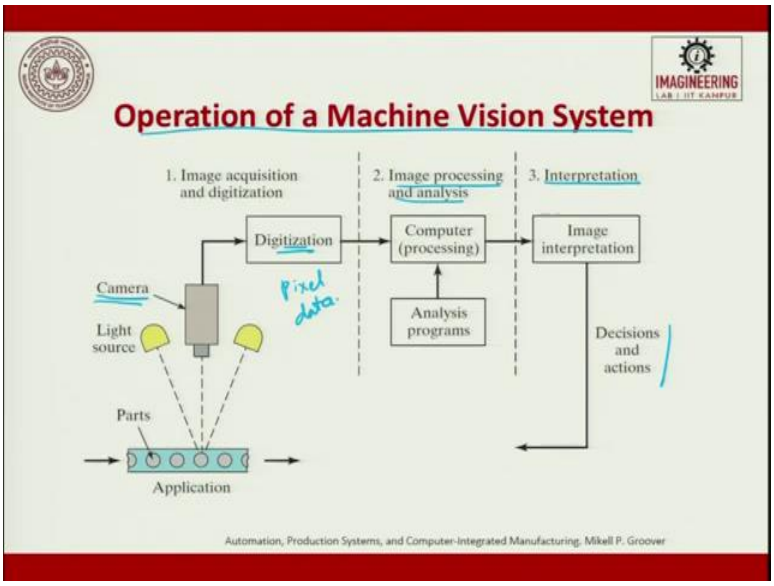

So, the operation of a machine vision system this is what happens in the acquisition I gave you an example of a camera with a flash so, you see here a light source is thrown on a part so this tries to lights are thrown and from the thrown lights you try to capture an image through a camera. So, now whatever image you are captured through the camera, will be then digitized. During the digitization, the analogues data is converted into pixel data.

After this pixel data is passed through image processing and analysis the computer starts working on the algorithm and it starts removing the noise then removing the background score, lights, etc. and then it starts working on extraction of the features so, that is what happens in image processing and analysis. Finally, from the extracted image we have a master, we do an interpretation from the master and then we try to take a decision. So this is the decision and action which is taken for the image base system.

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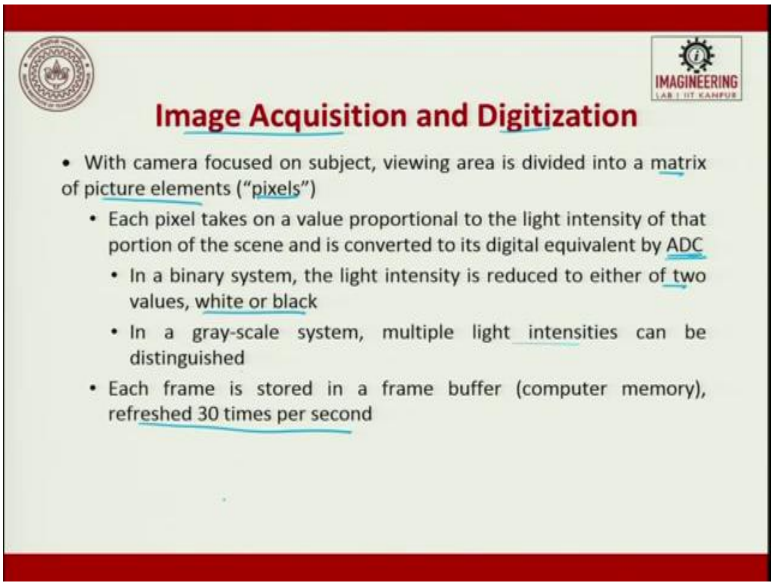

These are all part of computer-aided quality control today. Next, image acquisition and digitization with camera focused on subject viewing area is divided into matrix of picture elements which is pixels. Each pixel takes on a value proportional to the light intensity of that portion on the scene and is converted into a digital equivalent by analog to digital converter, A to D converter. So, now pixel so each pixel will try to take a value in a binary system the light intensity is reduced either to two values white or black.

The olden days we had black and white okay, the next one is the grayscale system multiple light intensities can be distinguished. Each frame is stored in the frame buffer, which refreshes 30 times per second. This is very important suppose, if it is static object fine, if it is a dynamic object, moving object then the number of frames per second plays a very important role to acquire the event so, image acquisition camera choice is very important.

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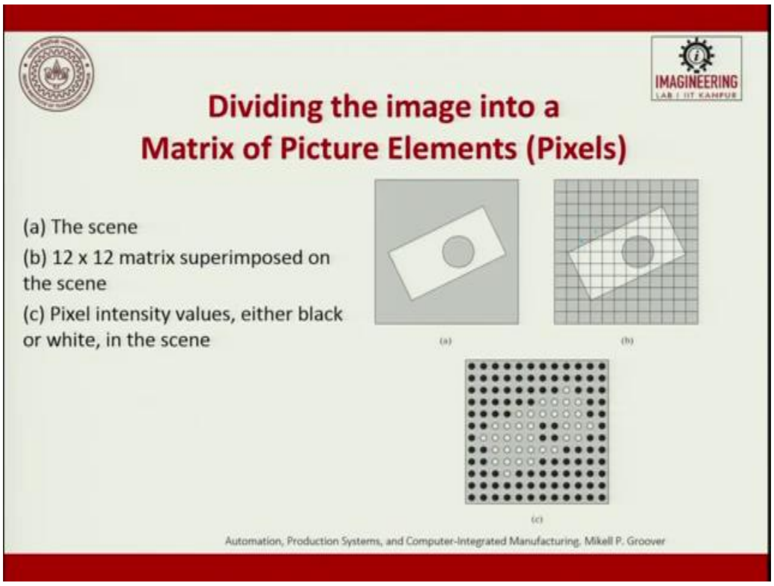

Then now, the dividing the image into a matrix of pixels so, it is a scene, this is the photo you have taken and now, you divided into a matrix, so 12 × 12 matrix is superimposed on the object and wherever there is a completely dark that means to say, there is no image present it is declared as black and wherever there is an image it is declared as white, there are certain portions where there is a mixture of black and white.

So, now depending upon the threshold value whatever you set, that particular pixel is activated or not. So that threshold you set, so a scene, a 12 cross 12 matrix is superimposed from the 12 × 12 matrix we try to take pixel intensity value which is either black or white and then you try to digitize the image.

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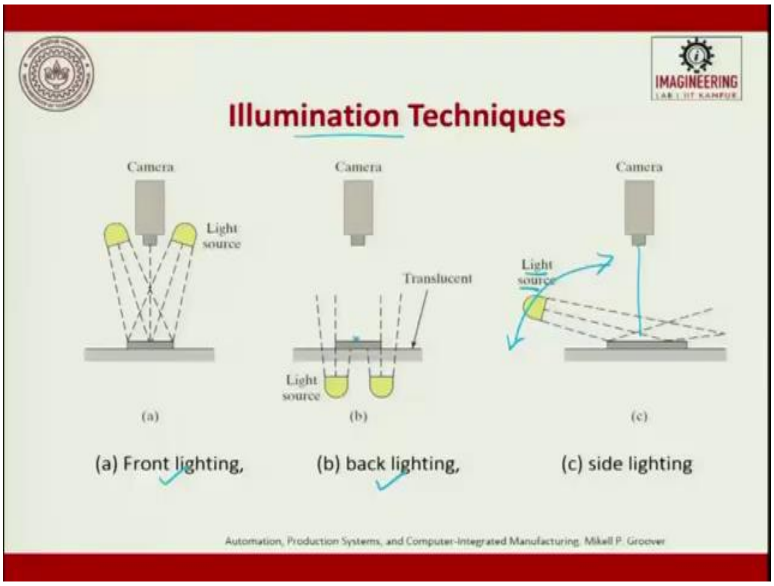

So, the illumination techniques it can be front side, front light it can be light from the back it can be light from the side. So, front side is when there is an opaque table and then object is moving on opaque table then we do this, and backlight is whenever we try to do biological samples we put it on a glass plate put, the sample here and light is thrown from the bottom.

Or if you measure the o ring dimensions which are black in color so, what we do is we allow them to pass through a conveyer sort it out, allow it to move on a transparent conveyor. Light is hit from the bottom it tries to look at the dimensions and those dimensions are captured by the camera.

So, front light, backlight, and sidelight depending upon the reflection what is produced by the light falling on the object we can also try to swivel the light source at an angle such that we try to get the best output. For example, when we try to do a silicon wafer when you are trying to look at the flatness of a silicon wafer, if you keep 90 percent, 90 degrees angle of the light then you will not get to see the image because it is highly reflecting.

So, in those places the times we always go for a light source. So all these things are used for today's measurements. And these measured a data will be processed by a computer, stored in a computer, and the date will be stamped, the shift will be stamped, and further, it will be communicated to the next level of information from this. So, computer plays a very important role in quality control.

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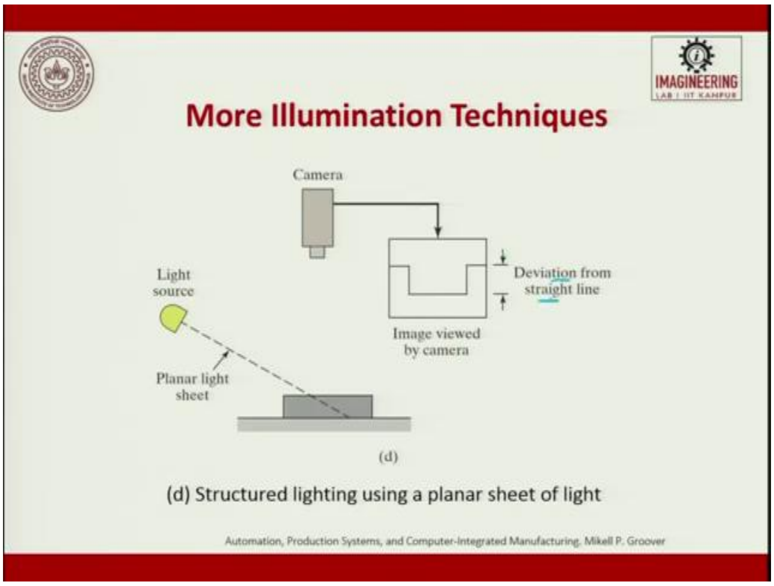

So, the more illumination techniques is also there. So, we have a structure light, this is a structure like the light source falls on a planer light sheet, so you will try to get a structure light which falls on it now, from the structured light we try to acquire the data and try to take the image. So, this is the deviation of the straightness. So, we can also have light source which is structured.

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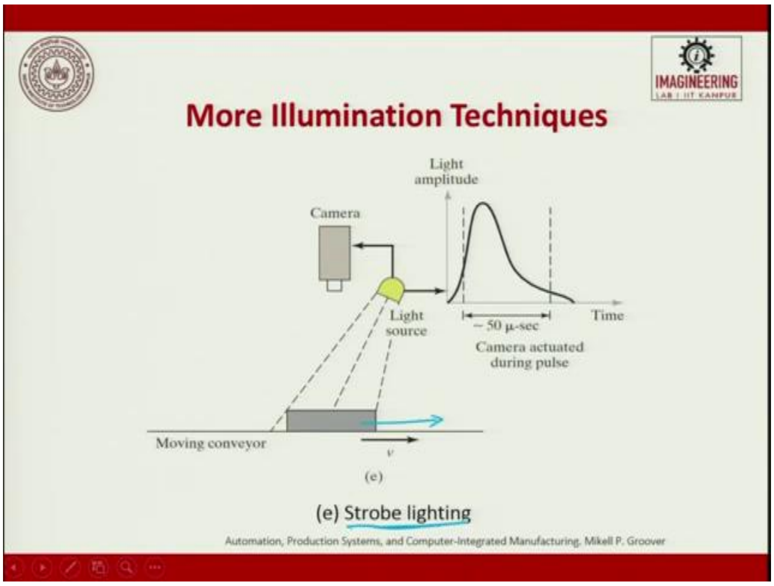

This is a strobe lighting so, in strobe lighting, this is a moving conveyor is there. So here is a light source and then we try to see this is the light amplitude and this is the camera, this is the time in seconds. The camera actuation during the pulse you see it goes during this side, and this is trying to take care with a moving velocity and object moves, and the camera captures. We use strobes lighting technique.

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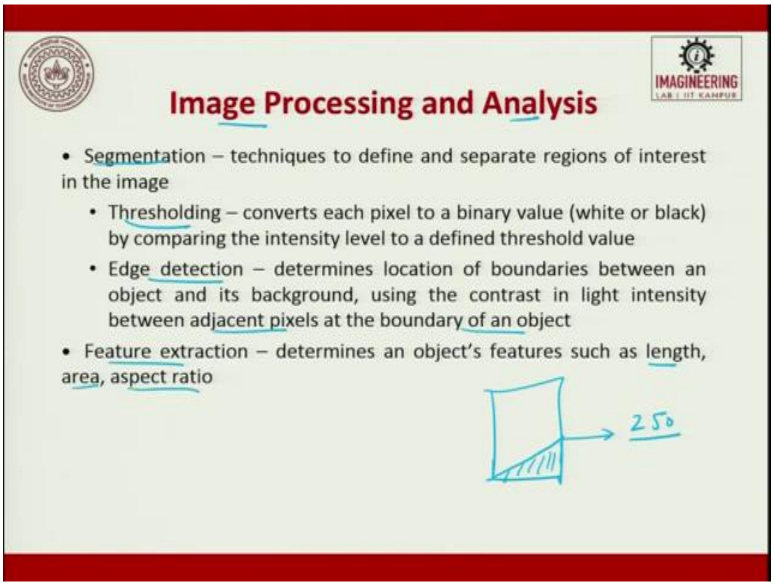

The image processing and analysis, the segmentation, now next step, so we saw acquiring then we saw matrix formation. Now, we are trying to process and analyze the image. So, here we have two features one is segmentation, other one is feature extraction in segmentation technique, a technique to define and separate regions of interest in the image that is segmentation. So, a threshold can be set, an edge deduction can be done a threshold is convert each pixel to a binary value that is what I said suppose if there is a unit cell only this portion is black.

So, now you set a threshold value of 250, so now if the value is less than 250 then the entire cell will be activated so, now this is thresholding. So how did you fix this 250 it is from the prior knowledge whatever we have. Convert each pixel to a binary value by comparing the intensity level with the defined threshold. The next one is edge detection, determines location of the boundaries between an object and its background using the contrast in light intensity between the edges and pixel at the boundary of an object. We try to do edge detection.

Edge detection is predominantly used for area calculation, volume calculation, and for extracting a feature from the image. So, segmentation these are, there are several techniques, the most commonly used two techniques are edge deduction and threshold. The other big thing is feature extraction after segmenting, the image has to be the feature extraction has to happen. Determines and object feature such as length, area, aspect ratio, this can be extracted by using the feature extraction model.

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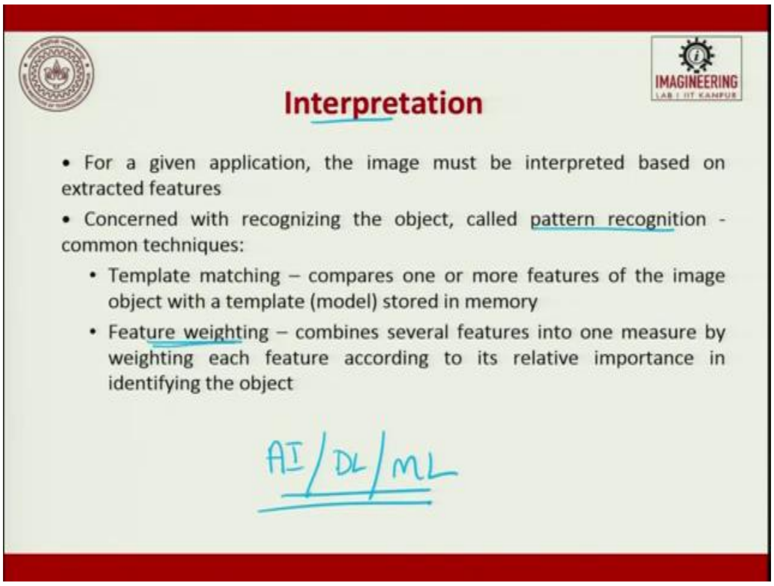

Then after what is comes the interpretation, for a given applications the image must be interpreted based on the extracted features. Concerned with recognizing the object called as pattern recognition which is very commonly used. Here, we use artificial intelligence, deep learning, machine learning all these techniques are used. In this interpretation techniques in machine vision which is part of computer-aided quality control.

So, the pattern recognition is of two things one is template matching other one is feature weighting. Template matching is compared on one or more features of image object with the template stored in the memory. So, I have an x-ray and then I have a set of all photos now place the x-ray on top of each photo and see whether the template is matching and find out what is it so, that is template matching.

The next one is feature weight, combine several features into one measurement by weighting each feature according to its relative importance in the identifying the object. So, feature weighting is another thing which is very much important today. It combines several features into one measure by weighting each feature according to its relative importance in identifying the object so this is feature weighting. This is very important technique which is exhaustively used in many software today.

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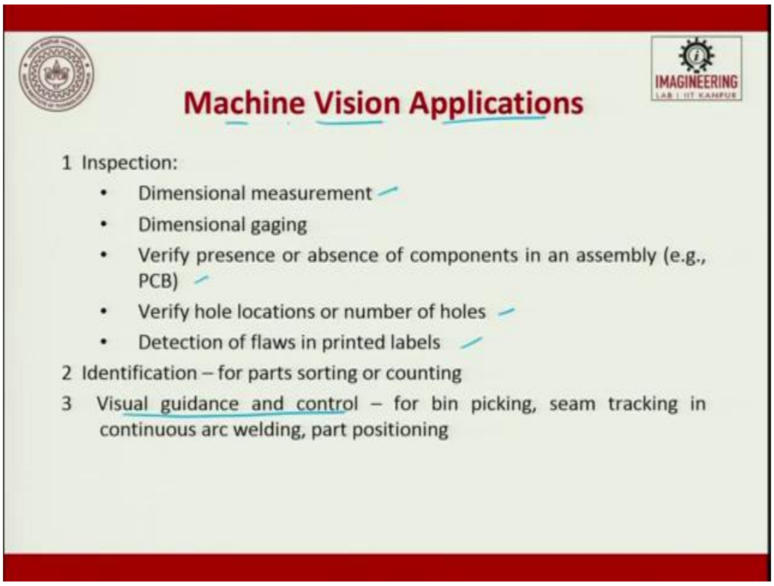

So machine vision applications when we talk about it is used for measuring dimensions it is used for measuring edging, it is used for checking the presence or absence of electronic components on a PCB verifies the hole location and number of holes, detection of flaw in the printed labels. Identification for parts sorting and counting can be done for identification. Then, visual guidance and control for bin picking, seam tracking in continuous arc welding, and part positioning. All these things are done today by machine vision applications. Exhaustively it is used in quality control.

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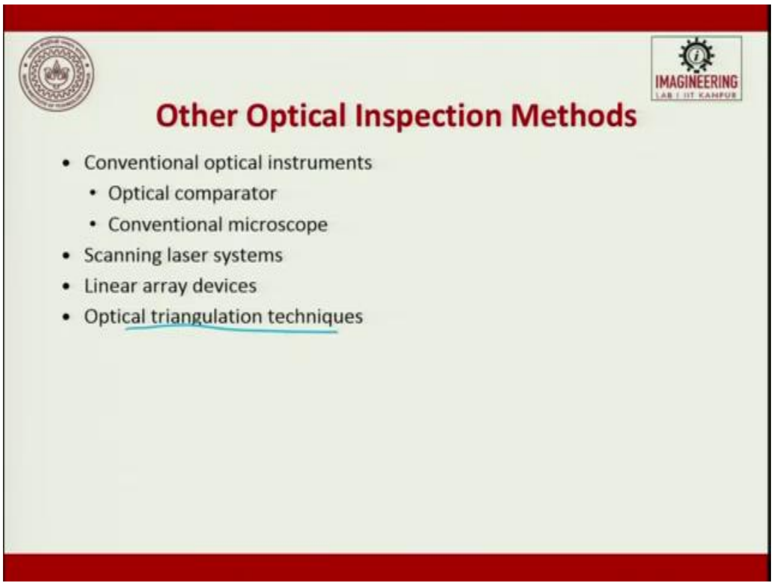

The other optical imaging methods are conventional optical instruments like optical comparator, conventional microscope, scanning laser systems, linear arrayed, then optical triangulation technique which is used for measuring the distance between a moving object and the fixed object or triangulation technique is exhaustively used in mobile phone tracking. So, we can also use optical techniques to do that. Moving object and the distance between, the object all these things can be done by triangulation technique.

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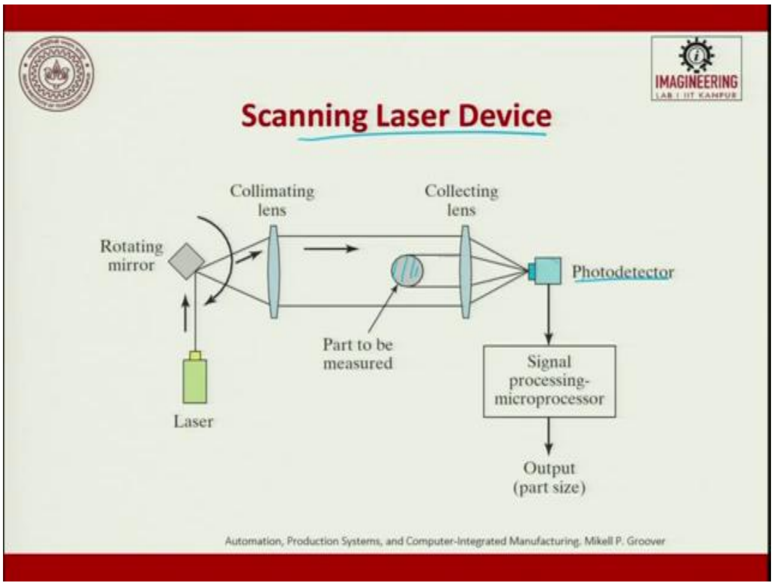

This is a scanning laser device technique so, wherein which what we use is we, use a laser the laser hits at a rotating mirror this rotating mirror the light is passed through a collimating lens then it goes to another collimating lens and then if you keep the path which is there in between.

So, this comes to the photo detector and the signal from here also comes to a photodetector. Now, the signal is processed and you try to get the output. Laser, rotating mirror so, this rotating mirror will do an x, y scanning it is like a Galvo scanning x, y rotating mirror. So, you will have collimating lens the part is kept here, so, the, just by rotating this you will try to get all the details which is been projected on to a photodiode.

So, say photodiode is nothing but light falling, yes, no, same thing pixel matrix pixel so, here will a pixel from there you try to take a signal processing and you get the output. Scanning laser device is exhaustively used.

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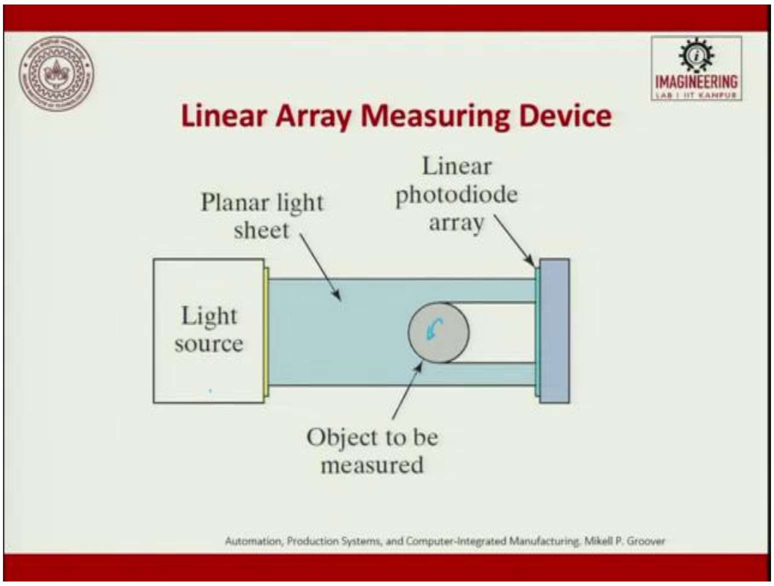

The next one is a linear array measuring device so, you have a light source wherein which you have linear and this passes through a plane, light passes parallel to it so, you have a linear photodiode so, light source falls so, again on off, ones and zeros with a, in the photodiode is there, the object is kept in between.

This is a planar light sheet which falls on the object and the image is taken. So, here the object can rotate, you get or you can get all data in one shot.

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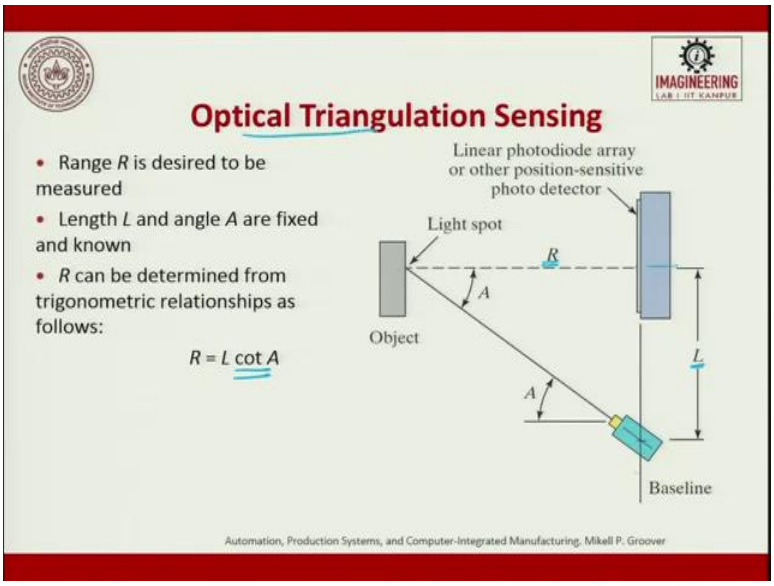

Next, I have talked about the optical triangulation sensing techniques. So, here the important thing is the triangulation technique which is used so, here is a camera which is there the object is here and then you have a linear photodiode or other positioning or sensitive photo device. So, the distance between the photodiode and the object is R, which is the range and then L is the distance between the photodiode and the camera that is L and A is the angle in which the object is placed, and it is fixed, so the R can be determined, this R keeps varying, this R can be determined by:

$$R = L \cot A$$

So, this L is fixed, this A is fixed so, now the only variable which can change is R from this distance varying R we can try to find out what is the object which is there. So, this is how an optical triangulation sensing device works.

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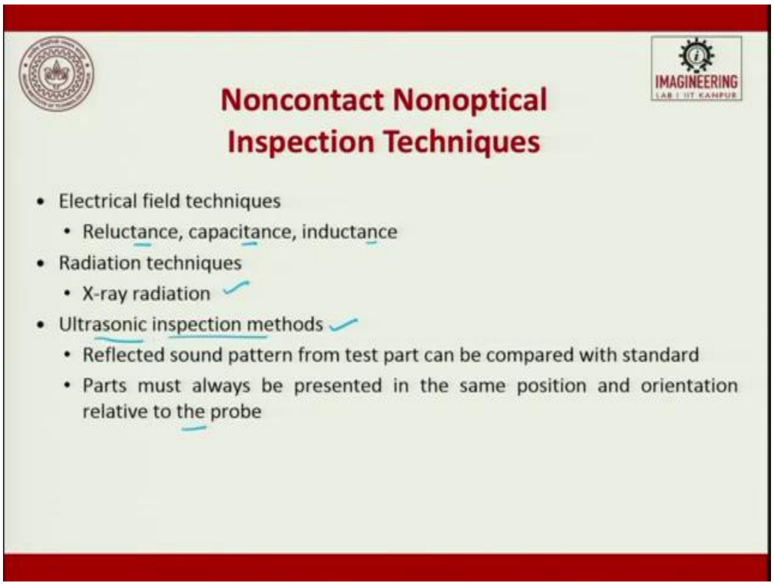

Non-contact, non-optical imaging techniques we use electrical field techniques such as reluctance, capacitance, inductance, can be used x-ray techniques are used, ultrasonic are used today to measure the dimensions of it. So, the reflected sound pattern from the test part can be compared with the standard or the part must always be present in the same position and orientation relative to the probe we can try to use ultrasonic techniques for imaging. So, today we use all the three capacitance-based, inductance based, x-ray, and ultrasonic for imaging.

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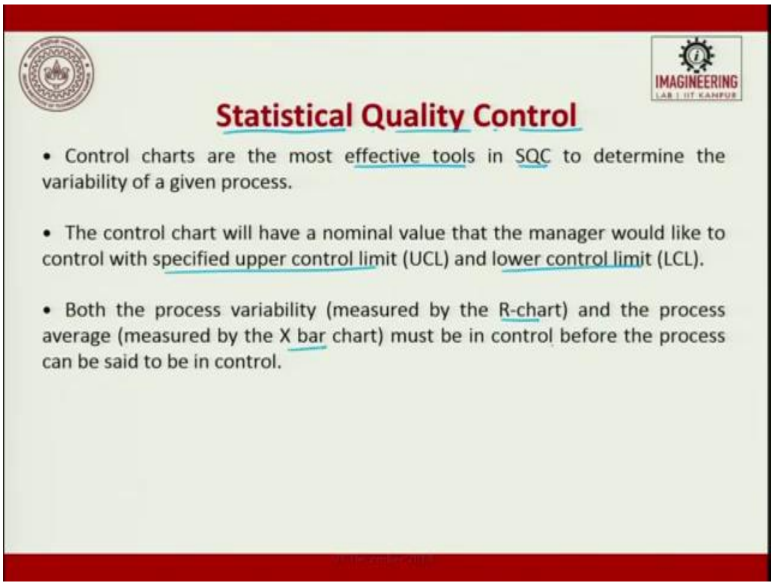

The last part of the, this lecture, we will try to see something on statistical quality control. Till now, what we saw is, we saw different techniques how do we measure the quality, now the measured quality has to be recorded and then analyzed statistically, so we use tools like statistical quality control and some of the process's charts. So, control charts are the most effective tools in SQC to be determine the variability of a given process.

It can be imaging, it can be machining, it can be assembly whatever it is, control charts is the most effective tool which are used in SQC. The control charts will have a nominal value that the manager would like to control with the specific upper control limit and a lower control limit. Both the process variability measured by R-chart or by X bar chart must be controlled before the process can be set to be controlled.

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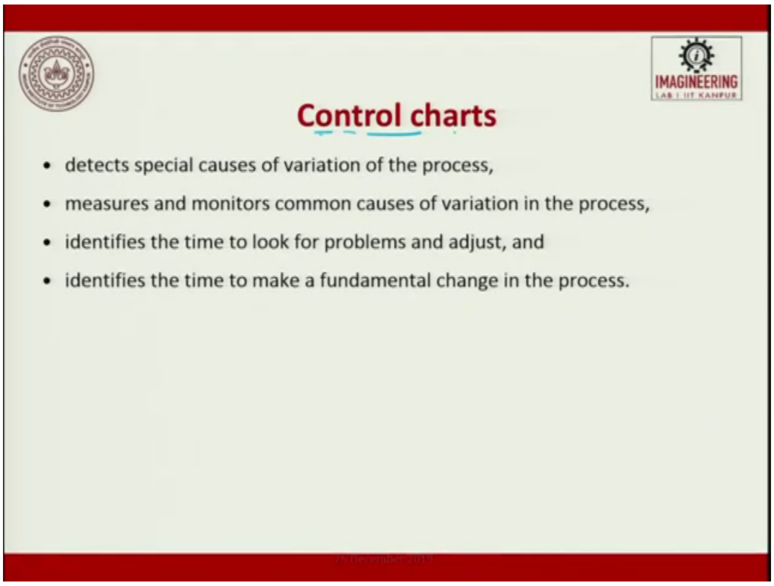

So, the control charts are used to find the defects special causes variation of the process. Measures and monitors common causes of variation in the process identifies the time to look for problems and adjust and identifies the time to make a fundamental change in the process, so, for all those things we use control chart exhaustively in quality control.

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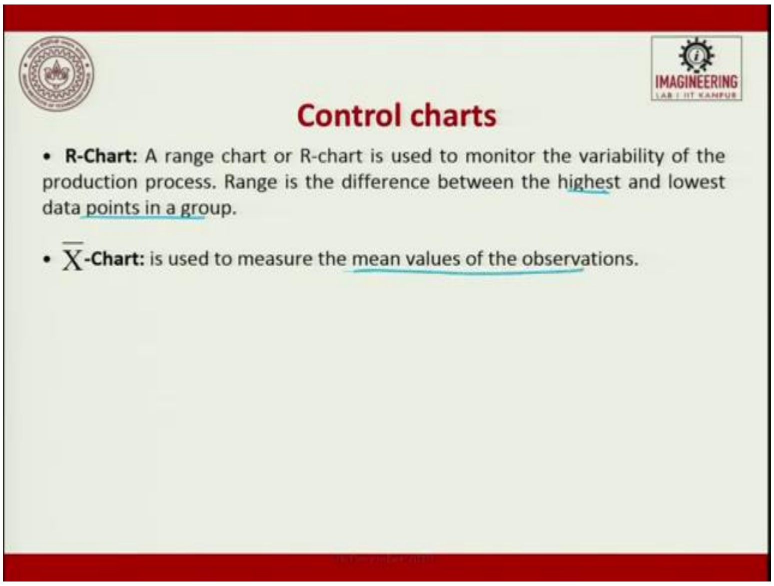

There are two major control charts, R-chart, a range chart, or an R-chart is used to monitor the variability of the production process. Range is the difference between the highest and the lowest data point in a group. So, this is R-chart, we also have an x-bar chart, which is used to measure the min value of the observations.

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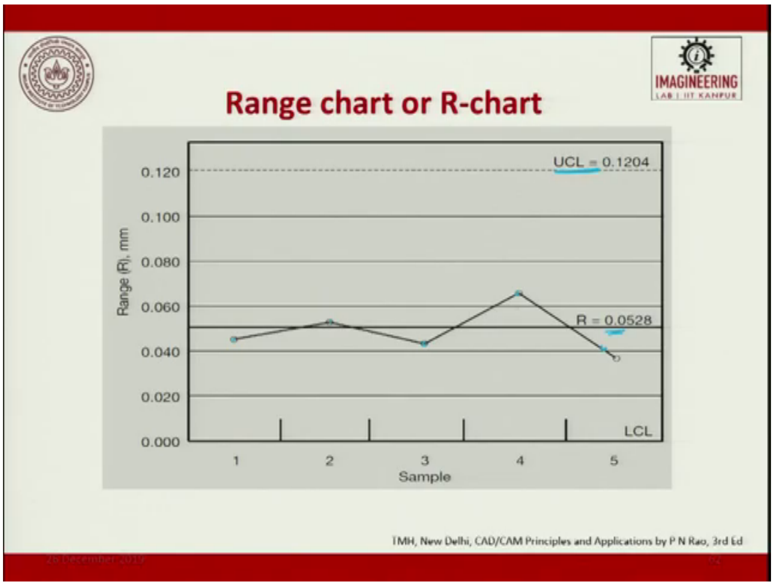

So, if you see an R-chart this is the range and you can see the samples how have the samples, are performed. So, the UCL upper critical level is 0.104 the range is 0.0528, so now we say whether the process is under control or not. So, this is typically a chart which shows how the data is recorded from CMM, from machine vision systems into a chart such that this chart will also be stored along with the product.

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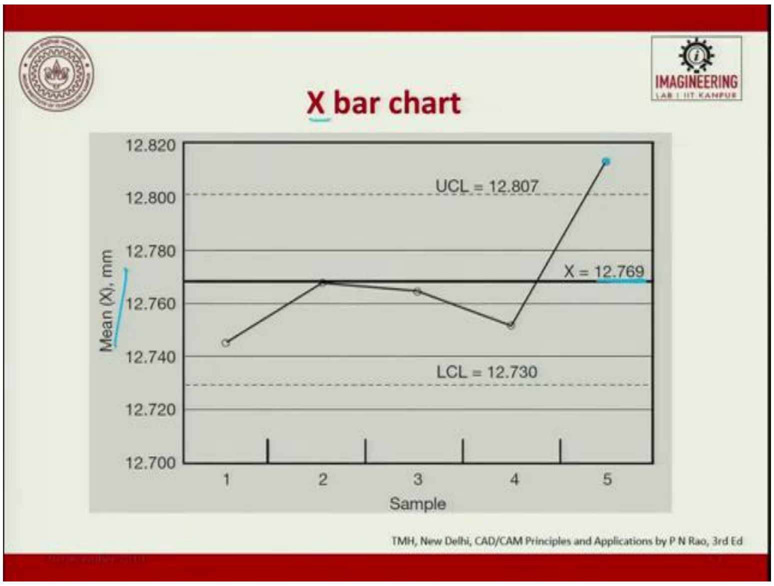

So, if you look at the x-bar chart we will see the min chart, so UCL is 12.807 lower, upper control, lower control between these two. There is an X which is the mean 12.768 and you will see the process is going out of control when it crosses the limit. So, this chart is called a x-bar chart.

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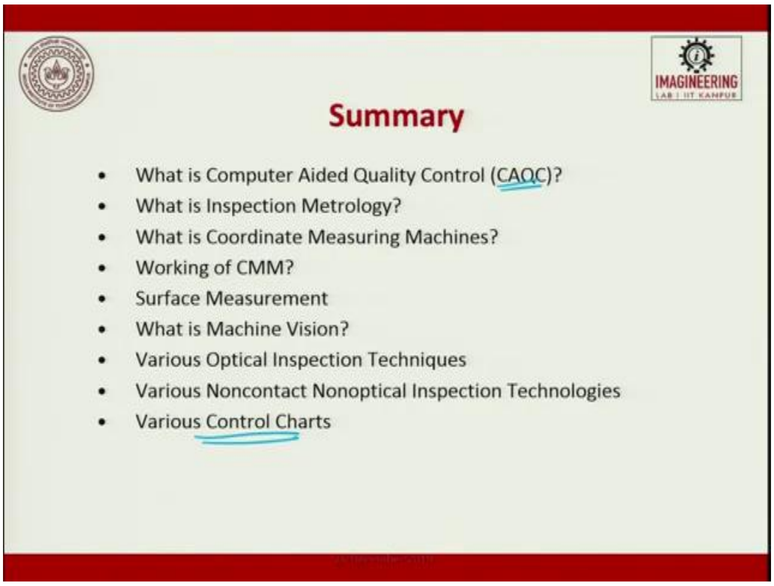

To summaries, what we have seen in this chapter, is we have seen what is computer-aided quality control, what is inspection metrology, what is coordinate measuring machine, working of a coordinate measuring machine, surface measurements, what is machine vision, various optical inspection techniques. Various non-contact, non-optical inspection techniques and the last one is various control charts. So, all these things we have studied under the topic of computer-aided quality control, today statistical process control or statistical analysis is exhaustively used to evaluate the process. So, wherein which we use various control charts to acquire the data, store and keep the data. So, Thank You.