Metal Additive Manufacturing
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Lecture 31
Reverse Engineering in MAM (Part 2 of 2)

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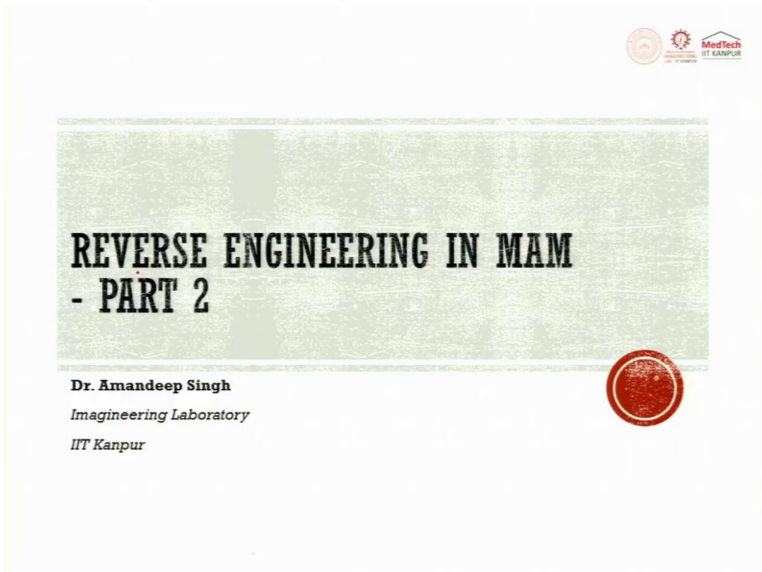

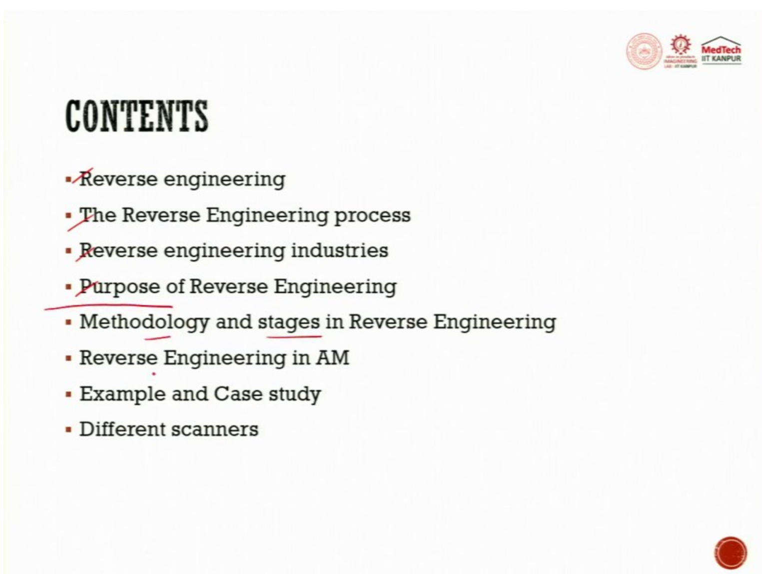

Welcome to the second part of the lecture on reverse engineering. So, we are discussing reverse engineering in metal additive manufacturing. So, what we have discussed already is reverse engineering, the process used in industries, the purpose, the methodology and stages in reverse engineering in additive manufacturing specifically, then some examples and different scanners in the second part.

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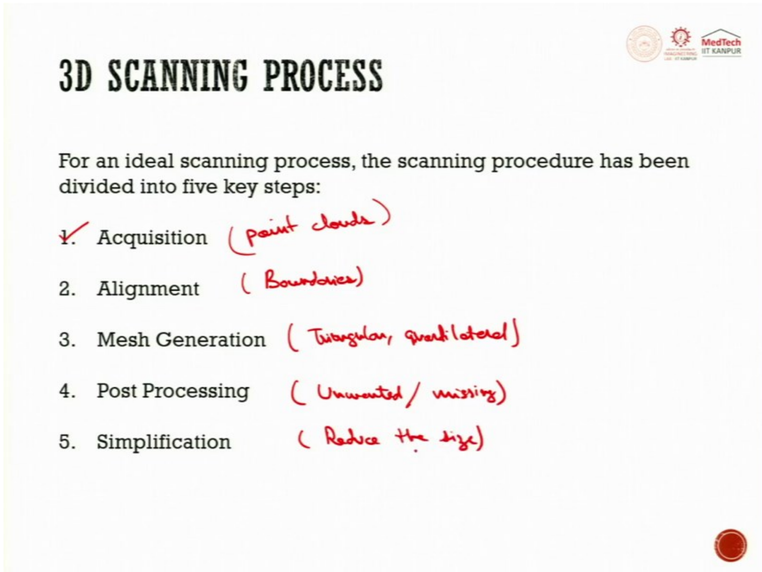

The 3D scanning process, an ideal 3D scanning process has 5 key procedures, I also mentioned the point in the previous lecture.

Now, here I will go into more detail for the data acquisition. Data acquisition means, we are having the point cloud data, the clouds of the points then we align these clouds to have the boundaries then we have the mesh that is the triangular or quadrilateral. Then post processing we clean the unwanted, that is the extra material or extra points or missing points, then simplification means we reduce the file size. So, these 5 steps I will just try to explain in the next few minutes.

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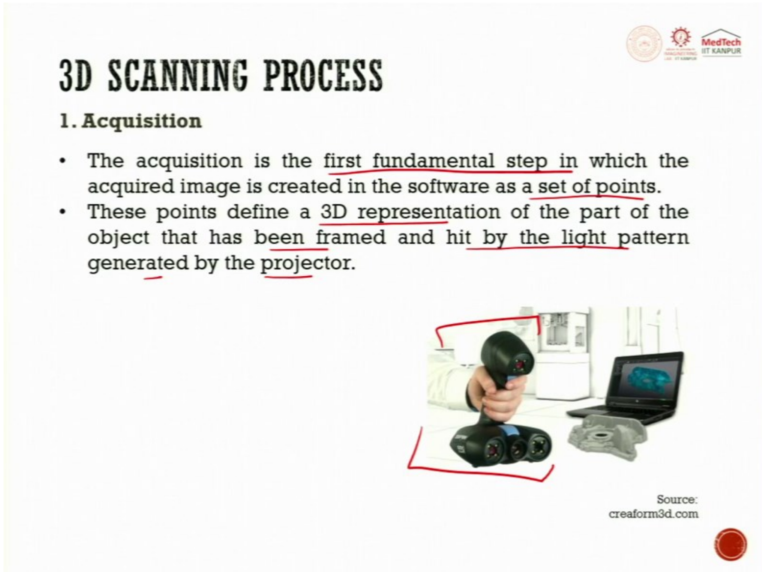

The acquisition is the first fundamental step in which we acquire the image that is created in the software as a set of point, it is in the acquisition process only when we need it to the scanner, this is a handheld 3D scanner. We need this equipment only for the data acquisition, once the acquisition is done, then everything happens on the software in your computer.

These points define a 3D representation of the part of the object that has been framed and hit by the light pattern generated by the projector. Once a raw or rough 3D reconstruction has been obtained, the scan can be improved by adding more views that correspond to the missing points.

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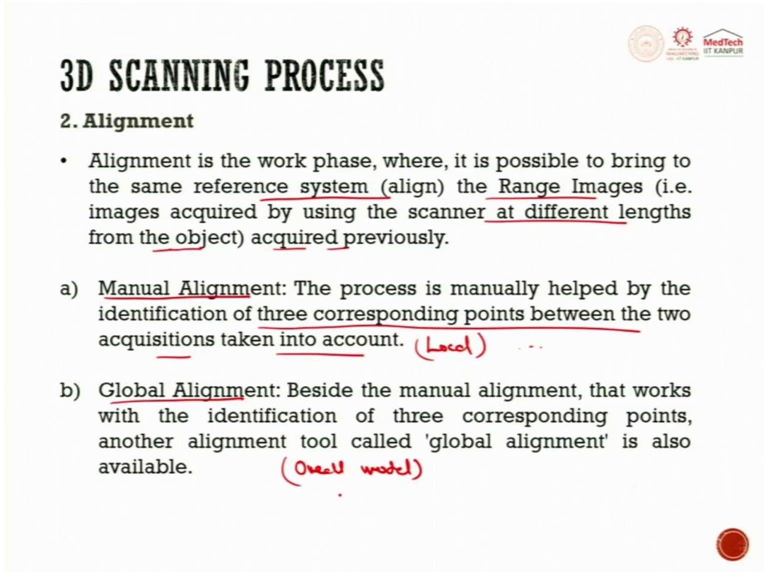

Now, in alignment in this work phase, where it is possible to bring the same reference system that is aligned, the range of images acquired by using the scanner at different lengths, at different orientations, at different replications, at different rotations, those are acquired previously, those are all tried to put together here.

But this alignment could be manual or it could be global. The manual alignment is the process in which manual help identification of the three corresponding points between the two acquisition that taken into account.

Besides the manual alignment that works with the identification of three corresponding points in other alignment, the global alignment is available, it is advised to run command after having manually aligning the range. In this way alignment of each acquisition is optimized with respect to other, so manually is some local application. This is the overall model, small components we align then we try to have all the connection of the small components using the global alignment.

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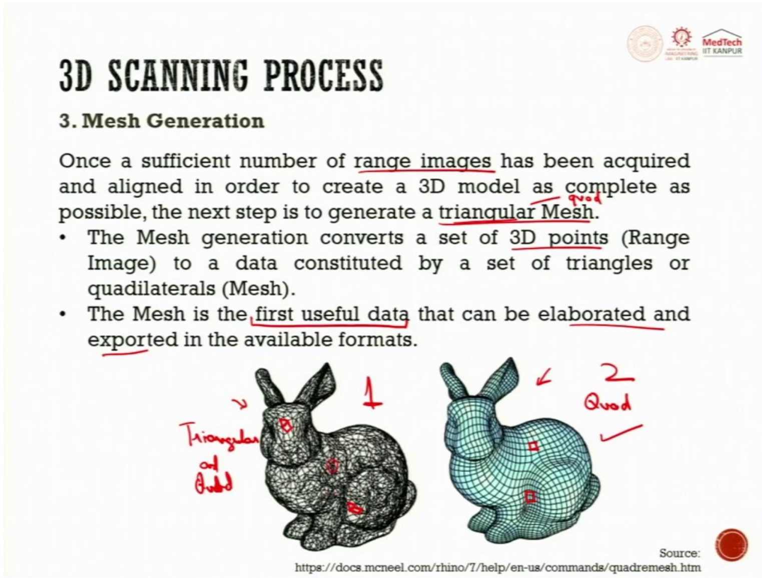

Next point is mesh generation. Once a sufficient number of range images has been acquired and aligned in order to create a 3D model as complete as possible, the next step is to generate a triangular mesh. It could be triangular, it could be quad mesh as well. The mesh generation converts a 3D points range image to data constituted by a set of triangles or quadrilaterals that is the mesh.

The mesh is a first useful data that can be elaborated and exported in the available formats. So, in the model given here, two meshes are there.

Right one is specifically a quad mesh in which quadrilaterals are used. You can see only the quadrilaterals are there, though the sizes are bigger or smaller where the surface is not very complex, the quadrilateral size is bigger, when the surface is little deeper or the depth or the shapes are having drastic changes. Here, the mesh size is smaller, we will see that in the next slide, this is a mix of the triangular and quadrilaterals mesh.

So, you can see this is a quadrilateral, but the other side is a triangle, just see the small things. So, we can have again here see this is a quadrilateral, but this is a triangle. So, in this case, for example, this kind of the quad mesh would give us the information that is required enough just to have a 3D print of it, that can be used to have a STL file and enough details are available to have small models developed or a CAD model developed out of it.

But if we need to do deep analysis on it, would be stress analysis again, different terminal assays are to be conducted using COMSOL, ANSYS and when we need more information, this kind of mesh, the mesh 1 and 2, I will name them, the mesh could be created in which more information is there. So, it depends on the kind of the applications, the kind of the elaboration you want to have the model, or you just wish to just export the model what kind of mesh you wish to have.

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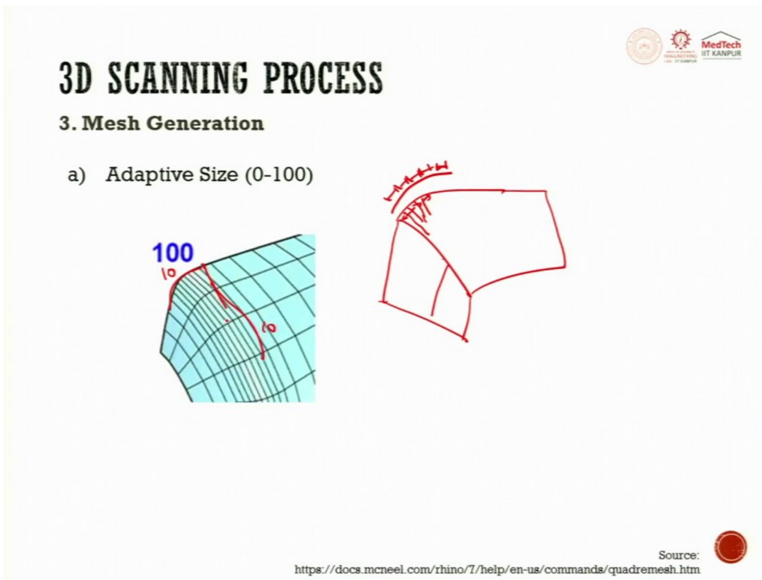

Now, when you have the mesh, the adaptive sizes are available, there are softwares available, which helps you to understand whether you need to have 0 to 100 ranges of the matrices which are there.

So, in these 0 means only one dimension, 50 means we have this triangle, when 100 comes you can see 100 means 10, 10 on this side and 10 on this side 10 on this side and 10 on this side 10x10=100. So, if this shape that is here, if it is only one dimension here, just like this it will not give you the depth of this curve or the curvature of this curve.

So, to have the good curvature, we can decide between 0 to 100 or we can even have more deep or more number of the elements here it depends of how deep or how many dimensions would at least define my curvature. So, all these lines are a curvature, how many straight lines this curvature could be divided into. For example, in 5 straight lines if this could be built that is well enough later if we let model could be applied in the CAD to have the proper curve there.

So, it depends upon what kind of information do you have. But yes, there is always trade-off between the number of the mesh elements we have, the time for the analysis, more elements we have, more deep or more dense mesh we have more would be time taken for the analysis, we are having the connections between each triangles or each nodes.

So, the degree of the number of the nodes that we have is directly proportional to the time that is taken for the analysis or for the simulations that we have. So, it is always recommended to have the least possible number of the elements for the mesh points.

So, as the time is minimum, the application time, the simulation time is minimized, but the quality should be enough and the number should be enough to have the quality or the product shape proper. So, this is adaptive size.

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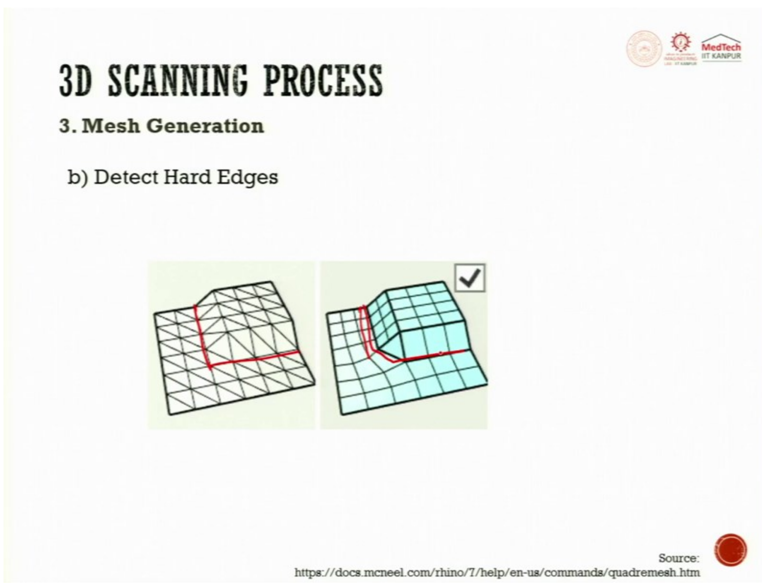

Next is we detect hard edges. Now, in this kind of the mesh, the mesh 1 if you see this is the triangular mesh, the second one is the quadrilateral mesh in this, these hard edges are not yet defined. In this case, in the second case it is a 30-degree break angle threshold is used to divide the quad mesh with hard edges that is creased edges.

So, these creases are made here, the break angle between the two adjacent faces is larger than 30 degrees then hard loop will be added here. So, in general, these are also a few points that are taken into consideration.

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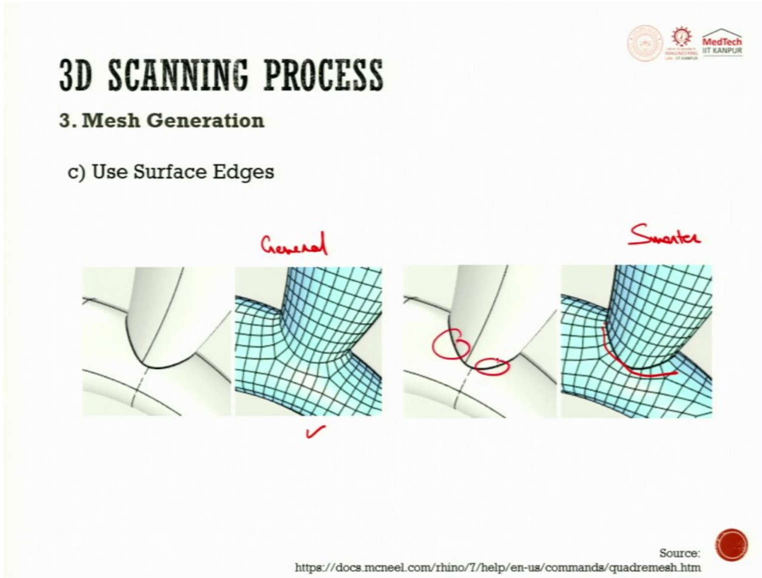

Then we use surface edges. So, there is a system which I would say is a general system. This is a smart system, smarter system. So, if we have a poly surface offer or in an extrusion system, it specifies if the meshes edges will be created along the sub phase boundaries on the input object in the general system. It ignores the soft phase boundaries, this is sub phase boundary data that has been ignored in the general system.

So, these surface boundaries are retained in the smarter system when we try to have this specific boundary okay yes, this boundary would be there its boundary has to be taken care of, and it brings us a more meaningful algorithm of the meshes that we have.

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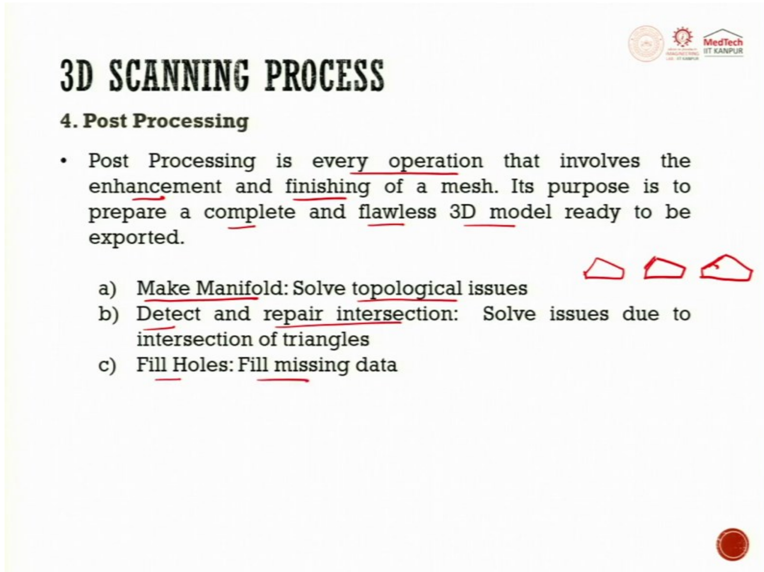

Then comes the post processing, post processing is each and every operation that is taken care or that is implemented, which involves the enhancement and finishing of the mesh. The purpose is to prepare a complete and flawless 3D model, which is ready to be exported, these operations should be chosen depending upon the results to be achieved and they can affect more or less the 3D model.

For example, make a manifold that is solid typological issues, there could be the overlap of the areas this is one mesh, the second replication of that, the third replication of that, when we try to overlap them, sometimes this line would be not exactly matching with the previous model.

So, this brings the typological issue that what is the actual shape that has to be taken care of. And detect and repair the intersection, that is solve issues due to intersection of triangles, fill the holes, fill the missing data holes, or empty slots. If those are there, post processing actually now brings us the model complete that could be now exported that could be now used for 3D printing.

But sometimes because the multiple replicates are there, scans sometimes happens in the 100 replicates sometimes, so the data becomes or the file becomes too big to transport. A file that is, for example of the degree of maybe 3 GB, 5 GB, 10 GB, it is difficult. So, simplification is also one of the steps that is important.

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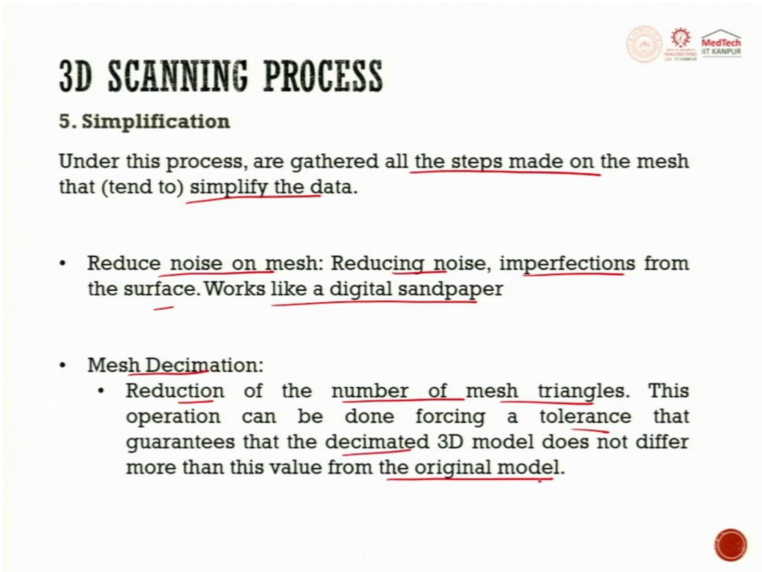

So, next step is simplification. In this process, the data that is gathered and all the steps made on the mesh tend to simplify the data. That is number one, reduce noise on the mesh, reducing the noise imperfections from the surface it works like a digital sandpaper, the model is ready with the sandpaper on this sculpture that you have designed or try to finish it and also you are trying to reduce the number of triangles, that is mesh distribution.

Reduction of the number of triangles, then this operation can be done forcing the tolerance that guarantees that the decimated 3D model does not differ more than its value from the original model, so that the model could be emailed, it could be transported from one place to another in that digital format.

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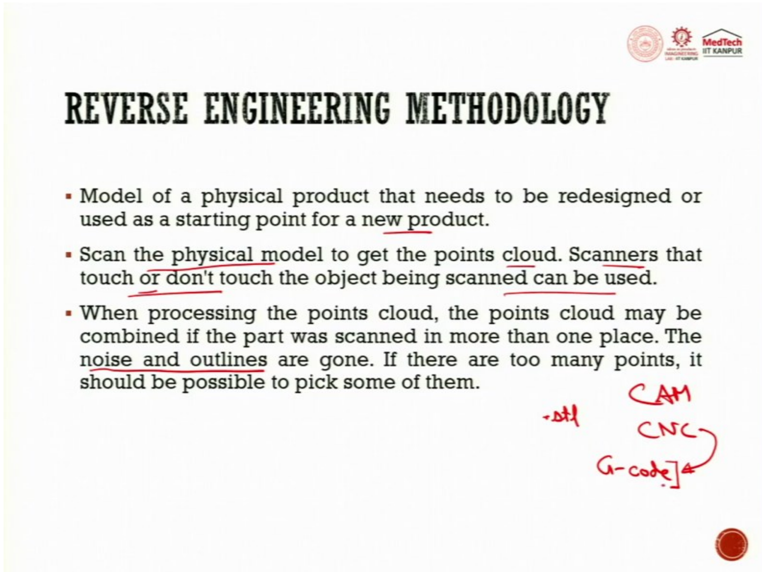

Next is reverse engineering methodology. Once again talking about because we need .STL file. Just to put that in a nutshell, a model of a physical product needs to be redesigned using a starting point for a new product. The scan of the physical model to get the points cloud scanners that touch or do not touch the object being scanned can be used. When processing of the point cloud, the point cloud may be combined if the part was scanned in more than one place, the noise and outlines are gone. If there are too many points, it should be possible to pick some of them.

So, to make the polygon model and to get it ready for rapid prototyping, that is to have the STL file we get the surface model ready and to be ready to be sent to the CAD CAM programs. So, making tool paths with CAM package and then we have the CNC machine setups because the codes if you try to have the G code even for the metal additive manufacturing the G code will be similar to what you get in the CNC, similar not both exactly the same, because the G code will be having less than number of lines and it does not need to have the shapes from different sides, only the layers of the object are required.

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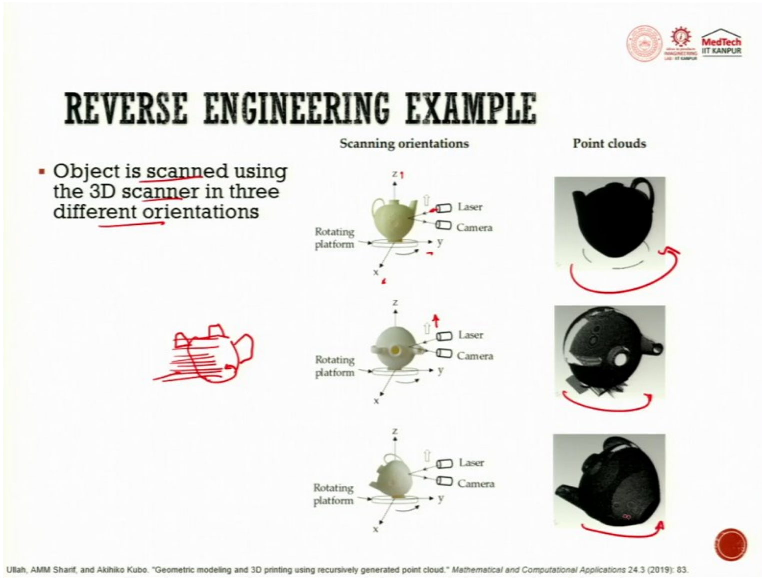

To quote an example of reverse engineering, we have selected a kettle here the object is scanned using a 3D scanner in three different orientations. You can see a laser light is being emitted from here, it falls on the object and the camera records the light back in this orientation when the object is kept on the platform straight, this is z axis, this is y axis and this is x axis and the object is being rotated here.

This is one rotation on one orientation to have the information about the object. The second orientation would be axis keeping the same z x y, we transform the axis or the orientation of the object, we just inverted or we put it at an angle around 90 degrees, and we try to then rotate it once again, this is the second orientation, this is also required for the model information, this arrow is showing above, because it is collecting the data from the bottom to above.

So, object is being rotated continuously, maybe suppose if it has 500 rotations, and the camera is collecting data, it is collecting data from the bottom to the top. So, this is the cloud being built here.

So, then an orientation which is an angle in this case a 45^0 angle or maybe close to 45±5 degrees, when we have another view of the object, these three orientations gives us the total information of the object in this case.

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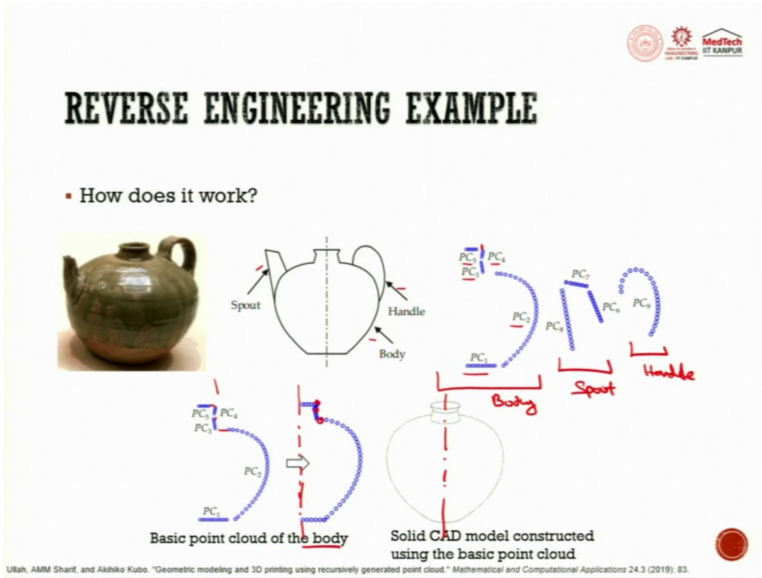

Now, what do we have as an output of the scan is, we get the point clouds this is point cloud 1, point cloud 2, point cloud 3, 4 and 5 we have the major components that is spout, then we have handle, then we have body.

So, this point clouds from 1 to 5 represent my body, the point clouds 6 7 8 point cloud 6, point cloud 7, point cloud 8 represents my spout, point cloud 9 represent the handle now, these are different point clouds first these are to be joined together here as it is being done here, this was the body, the different point clouds is a joint together, here joint is made here, 1 2 3 first joint, second and third joint, this body is built up.

Now, this body, we have, as I showed you in the previous lecture, the impeller cross section or the semi structure of the model is scanned and we have tried to now replicate that using a mirror command. The right side is only scanned, and the left side is made a mirror of that. Now, other two parts- spout and handle could be assembled over it.

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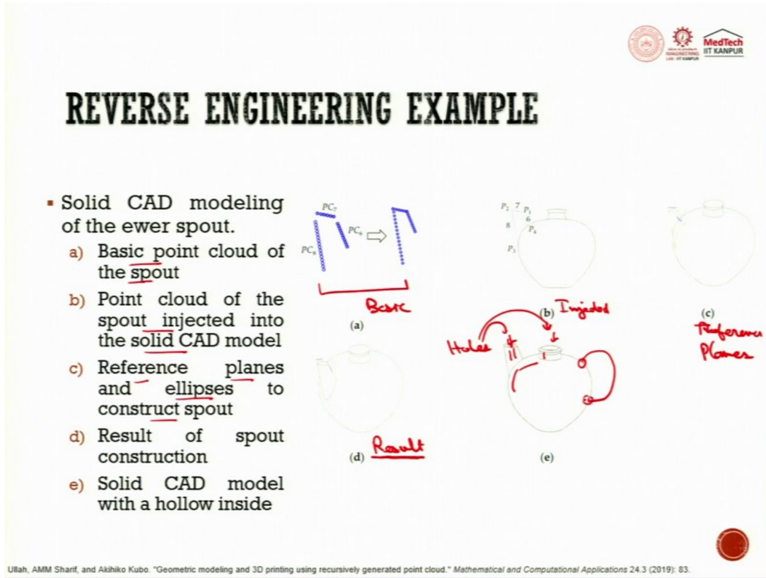

This is spout we try to assemble. The spout we say, okay this point 1 2 3 4 are there, the connection points here we try to assemble it.

So, basic point cloud or spout point , right cloud or spout injected into the solid model, this is the basic point cloud, this is injected into the solid model then point number c, we have the reference planes and ellipses to construct spout, this is injected, these are reference planes, fourth one is the result of the spout construction, then we can have solid CAD model with hollow inside more finishing as being done it has been void hollow here and here the holes.

Now, further post processing has to be taken care of we need to understand what is the thickness of this model so, what are the different thickness points here is it a varied thickness or continuous thickness here then where do we attach the handle, the handle attachment suppose this is a handle if we put it here, where do we attach at this attachment how close the things would be these are again the mesh taken care about.

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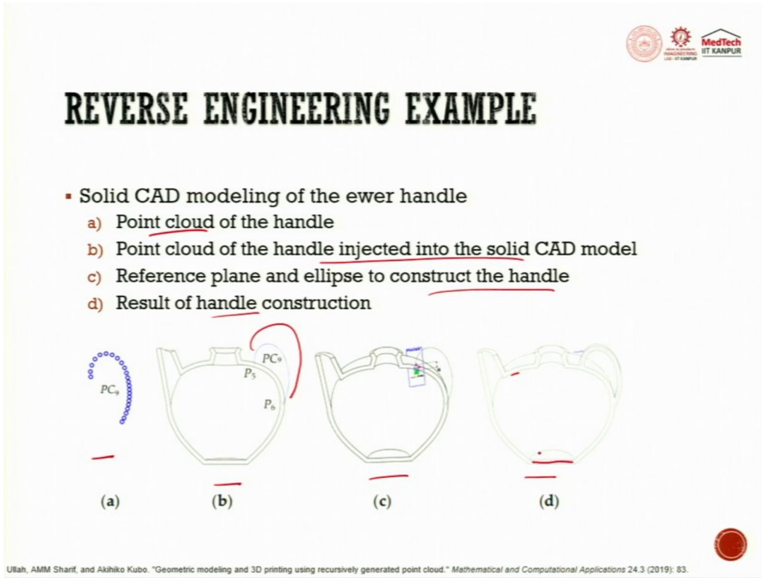

Now, next point comes the handle. Point A is the point cloud of the handle again then we have the point cloud of the handle injected into the solid model. Here the handle is injected here then reference plane and ellipses here to construct the handle see then result handled construction we have the handle construction.

In this case, we have this proper thickness handle injected over it, the spout injected over it, the top opening of the flask and the bottom straight everything is already, so this is a sectional view of it.

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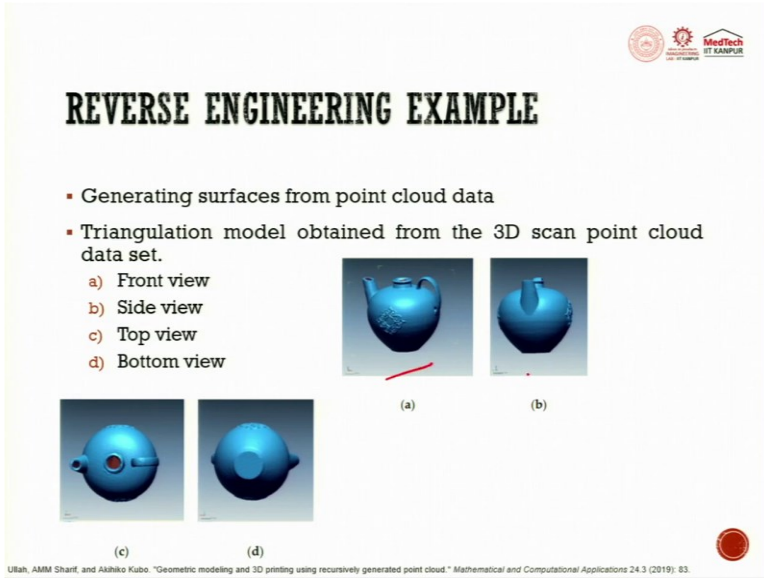

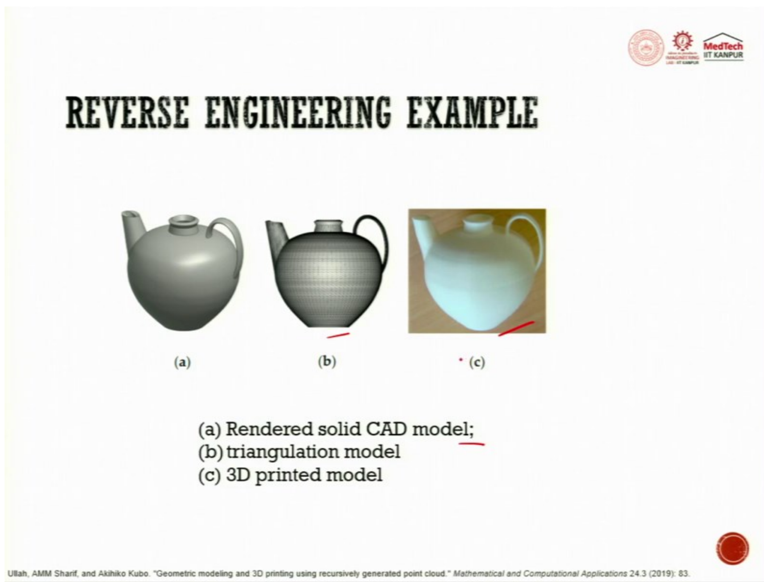

Now, we have generated the plot cloud data, we have used a triangulation model to obtain a 3D scan cloud data set in which this is the front view, this is the side view, this is the top view and this is the bottom view and the model is ready. Now, this model, we need to convert the file into STL. We have the rendered solid CAD model and we now see how it would look like when we try to have the triangulation model of it and when we try to have a 3D printed model of it. So, this is one of the examples taken to understand the reverse engineering more.

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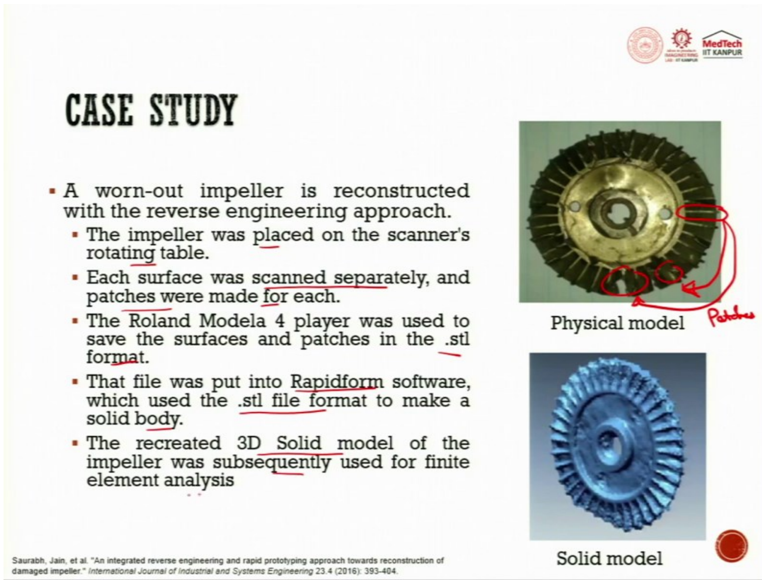

Small case study if you wish to understand more, a worn-out impeller is reconstructed. As it worn-out impeller that you can see small parts are worn out here, this was placed on the scanners rotating table each surface was scanned separately and patches were made for each taking from the area from where the model is completely correct, the patches could be added at various points, patch 1 maybe and patch 2 we have patches.

The Roland Modela 4 player was used to save the surface and patches in the STL format, the file was put into rapid form software. Rapid form software is also one of the 3D model post processing software, which is used. The STL file format to make the solid body, the recreated 3D solid model of the impeller was subsequently used for finite element analysis. This is a solid model generated out of it.

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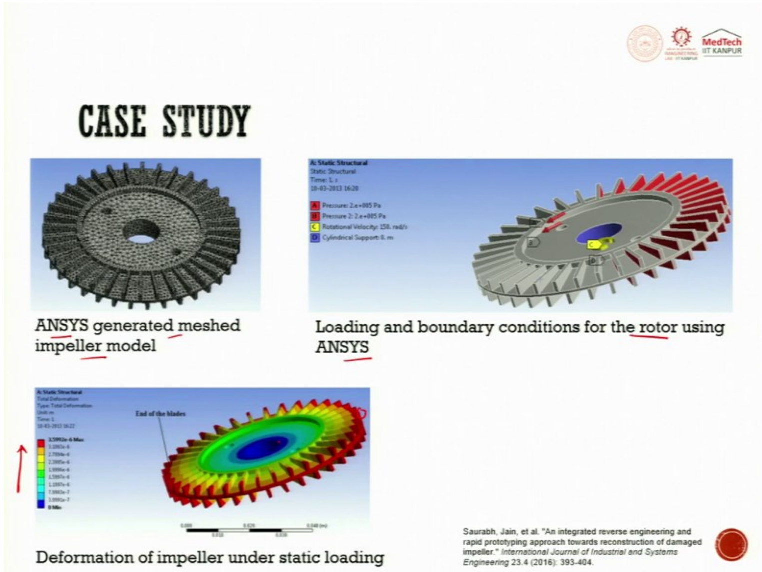

Then these all model, all the patches done over it in ANSYS system is used to understand the impeller model and then a small simulation with putting right boundary conditions to understand the pressure points, to understand the failure points and where the bids would fail. In ANSYS, I think you understand now, the red color generally shows it could fail maximum here, the blue is the safest color, you can see the color grid here. So, this is the safest and we have the maximum deformation that is here at the edges. So, this is a simple ANSYS case study for this.

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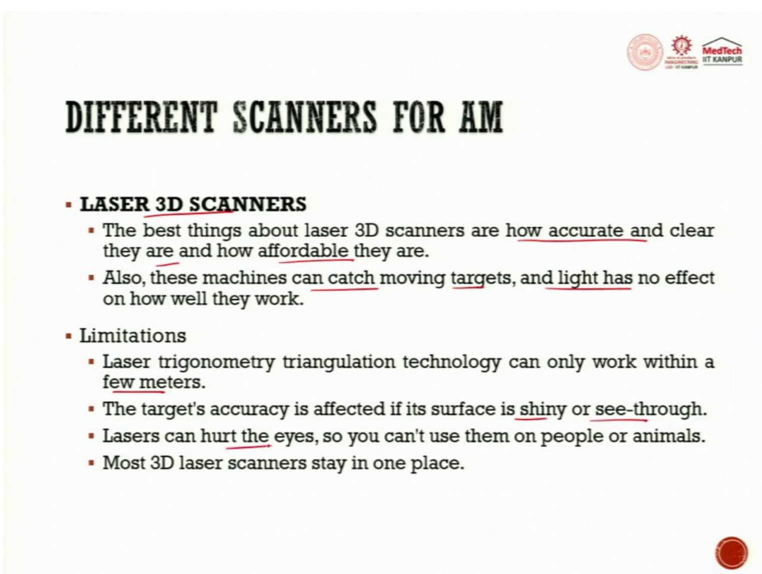

Now, again, the scanners, which we discussed before in the previous slides. One or two other scanners, I would like to just discuss are laser 3D scanners. The best things about laser 3D scanners are how accurate and clear they are and how affordable they are. Also, these machines can catch moving targets and light and has no effect on how well they work.

Limitations of the laser scanner would be the laser trigonometry metal triangulation technology can only work within a few meters, the target's accuracy is affected when its surface is shiny or see-through. That is transparent or shiny, laser can hurt the eyes, so you cannot use them on people or animals so, most 3D scanners stay in one place. So, this is an example of a laser 3D scanner.

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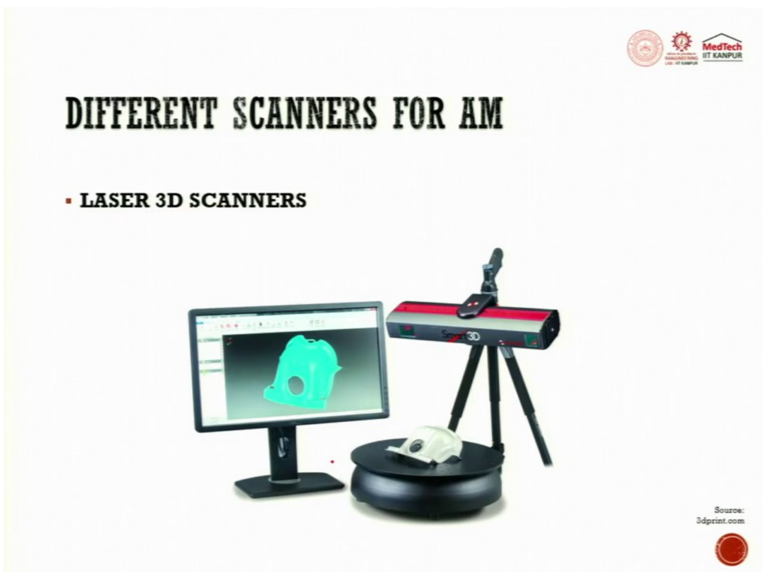

We will also have a look on a similar scanner in the next lecture, that laboratory demonstration for the 3D scanning.

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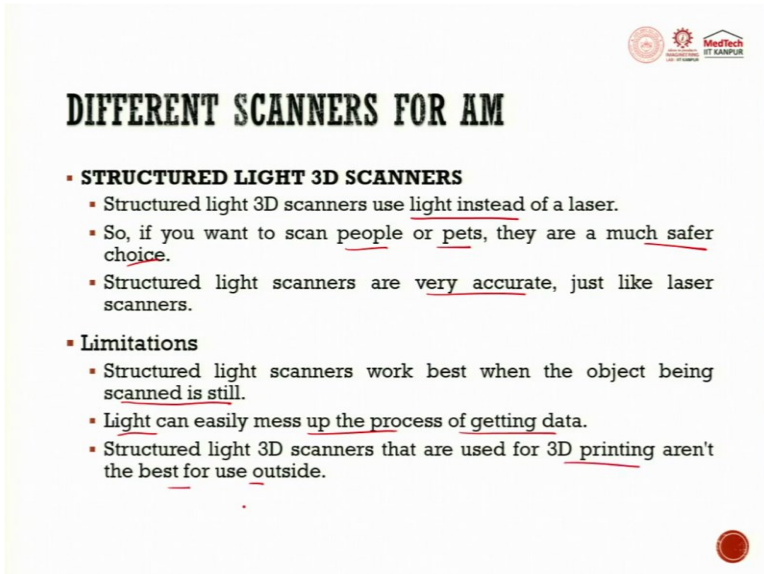

Now, next comes the structured 3D light scanners. A structured 3D scanners use light instead of laser. So, if you want to scan people or pets, it is not harmful so, they are much safer choices.

Structured light scanners are very accurate, just like laser scanners, the limitation of structured light scanners would be able to work best when the object is being scanned, and it is still so it cannot capture the moving objects as accurately or it does not even work to catch the moving objects but a lasers can be used to catch the moving objects as well.

Light can easily mess up the process of getting the data suppose if the room is too illuminated, or there is a lot of sun hitting the area that can obstruct the data that we are trying to get. Structured light 3D scanners that are used for 3D printing are not the best used for outside.

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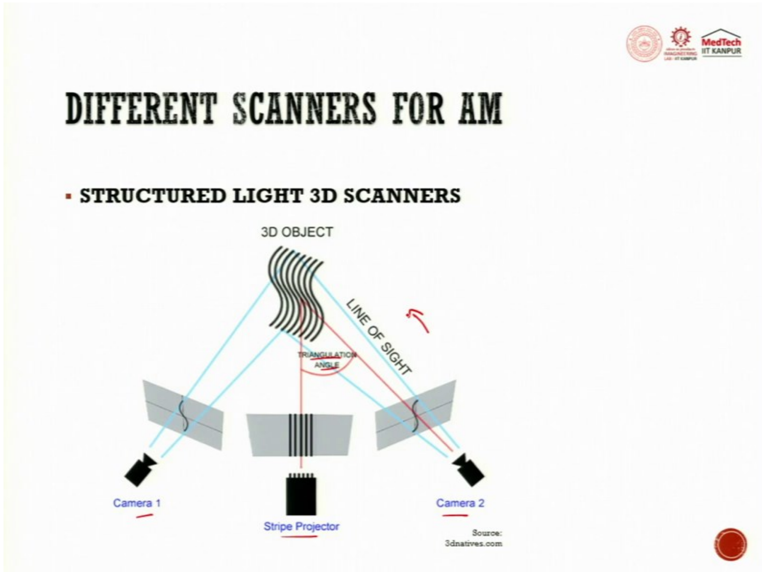

Now, this is an example of a structured 3D scanner, in which we have two cameras and a stripe projector and the triangulation method is used in which the angle and the line of sight is used to get the data captured on the projector.

The structure light technology is used in many handheld 3D scanners this is used for 3D printing today as well this technology also uses trigonometric triangulation. But instead of laser line it uses pattern of light to scan the objects. The pattern outline is put on the object with the help of an LCD projector on other stable light source.

So, a few inches away from the projector, only one or more sensor of cameras look at the shape of the pattern of the light and figure how far each point is there and the how the field view could be taken into account. The structured white or blue light scanner is used in the scanning process.

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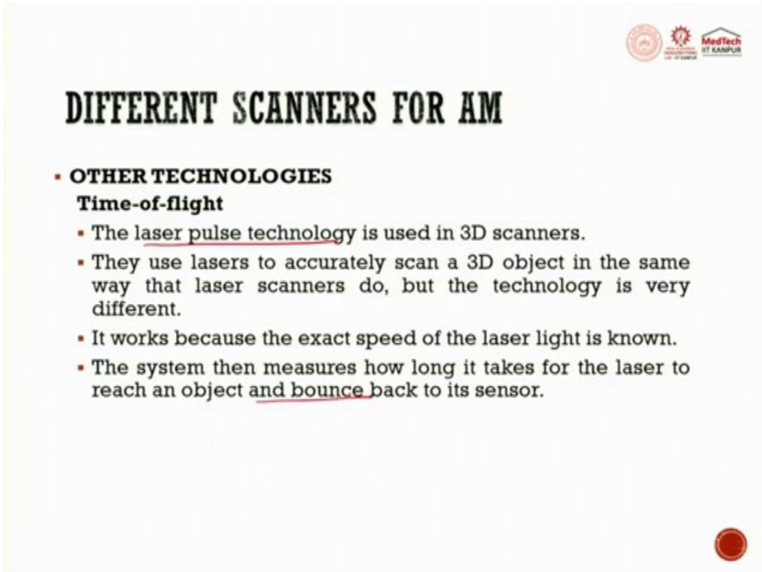

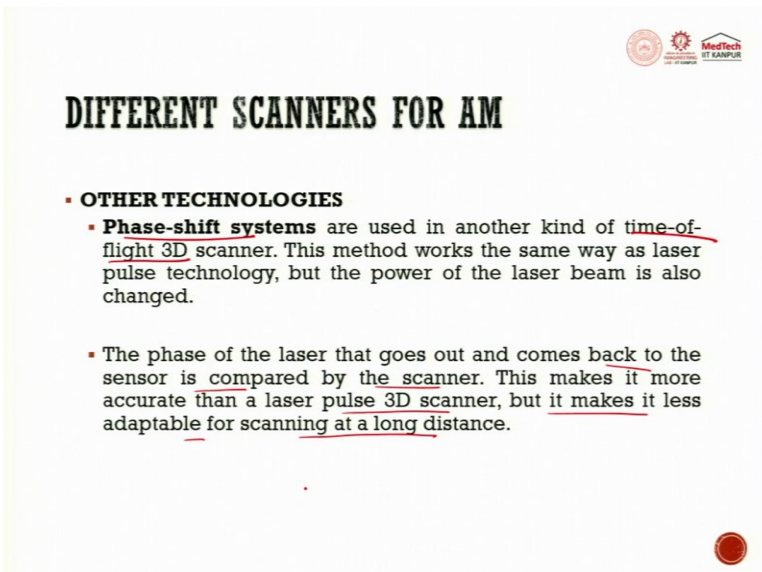

Other technologies are there; for example, laser pulse technology is also used in 3D scanners. They use lasers to accurately scan a 3D object in the same way that a laser scanners do but the technology is very different. It works because the exact speed of the laser light is known. The system can measure how long it takes for the laser to reach an object and bounce back to its sensor.

Other than this, we have phase shift systems. The phase shift systems are used in another kind of the time of flight 3D scanner. This method works the same way as laser pulse technology, but the power of the laser beam is also changed. The phase of the laser that goes out and comes back to the sensor is compared by the scanner. This makes it more accurate than a laser pulse 3D scanner, but it makes it less adaptable for scanning at a long distance for time of flight laser scanners and structured light scanners are much more accurate than 3D scanners.

But if you want to scan a large object, it will be tough to use the scanners comparing the phase shift system with other technologies like the laser light scanners or the structured light scanners, the laser and structural scanners are more accurate and provides the data with a better resolution. But if we need to scan a bigger object like a big ship or a building or an airship, the phase shift systems are the better choices.

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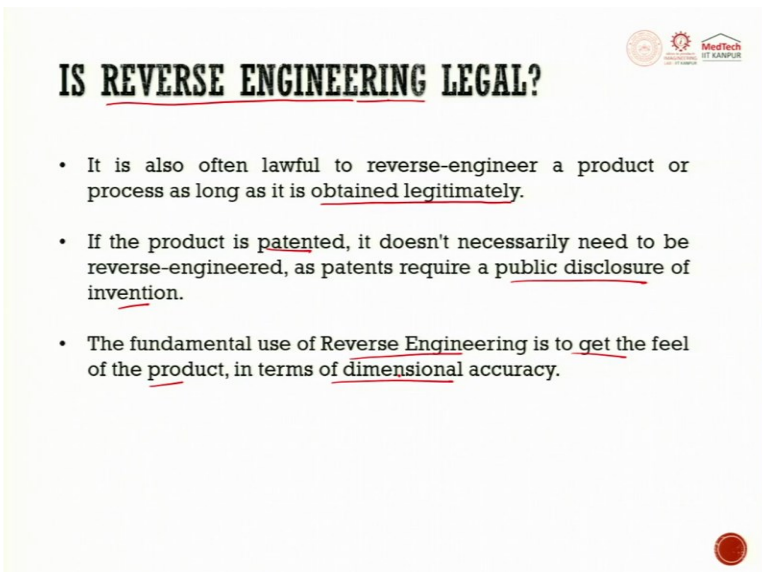

So, before I close my lecture, this is always a question is reversing engineering a product that is patented and that is having a copyright already in it, is it lawful? Is it legal? It is often lawful to reverse engineer a product or process as long as it is obtained legitimately that if we are not trying to go into any breach of the patent rights the product is patented, it does not necessarily need to be reverse engineer as the patent document in itself has the public disclosure of the invention.

So, it should be always noted that just because a piece of the product is patented, that does not mean that the entire product that is the process, product design, everything is patented, there may be multiple parts or multiple portions of the product that we are trying to see which are still undisclosed. So, that could be reverse engineered the fundamental use of reverse engineering is to get the feel of the product in terms of dimensional accuracy. So, it helps in improvisation and to determine the flaws in the product.

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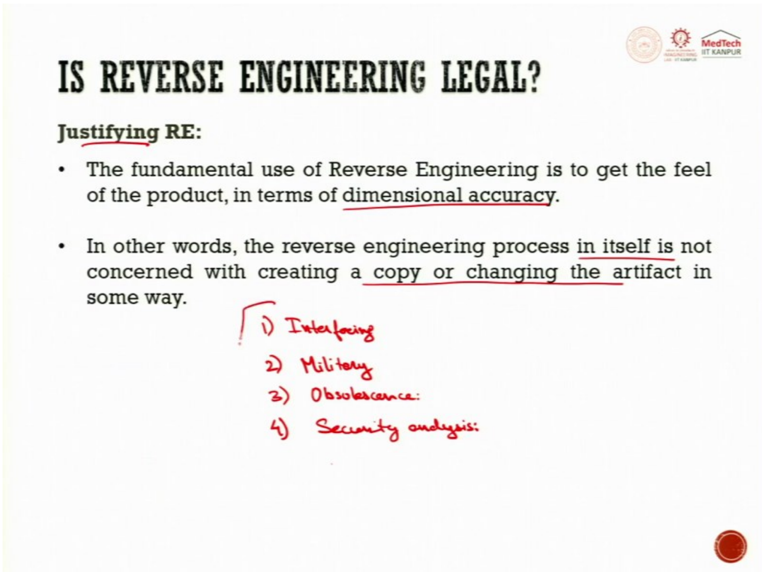

Now, to justify reverse engineering, the fundamental use of reverse engineering is to get the feel of the product in terms of the dimensional accuracy. In other words, reverse engineering process is not concerned with creating a copy or changing the artifact in any of the ways even when the product is reverse engineered that is of a competitor, the goal may not be to copy them, but to perform a competitor analysis that the products that we are developing and the product that competitor has hope closely the product performance is there.

So, there are certain reasons for which the reverse engineering could be justified for example, interfacing. Interfacing means, if we have a product, we are trying to reverse engineer it and we do understand whether the system is required to interface through another system to auto system that we have or both the system will negotiate if to be established together. Such requirements generally exist in the metrological applications such as interoperability.

Now, we have the military applications where the military or commercial espionage as you also they are learning about the enemies or the arrival that we have the latest research by capturing a prototype that is and we need to dismantle it we need to understand what is the development, what is the similar product, what harm could it bring to our systems. So, this is also one of the applications or their reasons we need to conduct the reverse engineering.

Then obsolescence of the system if they are, obsolescence means integrated circles some of systems which are the proprietary systems and like I told you original equipment manufacturing systems, which are no more available, so those needs support to reverse engineer the system and to understand how could we produce similar components, that is also one of the reasons that makes reverse engineering justifiable.

Then product, if it is developed in such a way that we do not want it to be reverse engineered, we do not want it to be copied. So, we asked us one thing have to be taken care or the reverse engineering of the product to understand the recovery of the security analysis of the product, how safe the product is, how secured the product is, so I would say security analysis.

To examine how a product works, what are the specification of its components estimated costs, identify the potential patent infringement if that could happen by a third party that acquiring the sensitive data by disassembling, by analyzing the design of a system or the component, another intent may be to remove copy production or any circumvention of the access restrictions, then competitive technical intelligence is also required.

So, these are the 4 major reasons that justify the reverse engineering that we have with this the 3D part of the reverse engineering is over.

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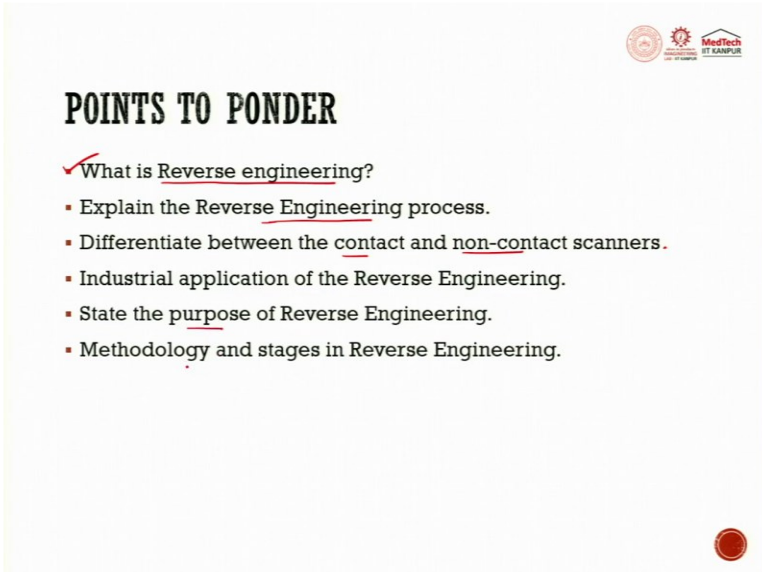

So, we have covered majorly in this lecture, what is reverse engineering, we understood the concept of reverse engineering, reverse engineering concept is also there applicable to the software reverse engineering, business reverse engineering, how the business model has been developed, but we have only focused on the mechanical or the engineering or the product reverse engineering here.

Explain the reverse engineering process is another point that we have pointed over, differentiation between the contact and noncontact scanners, industrial applications of reverse engineering, the purpose of reverse engineering methodologies and stages of reverse engineering, we have seen in this lecture.

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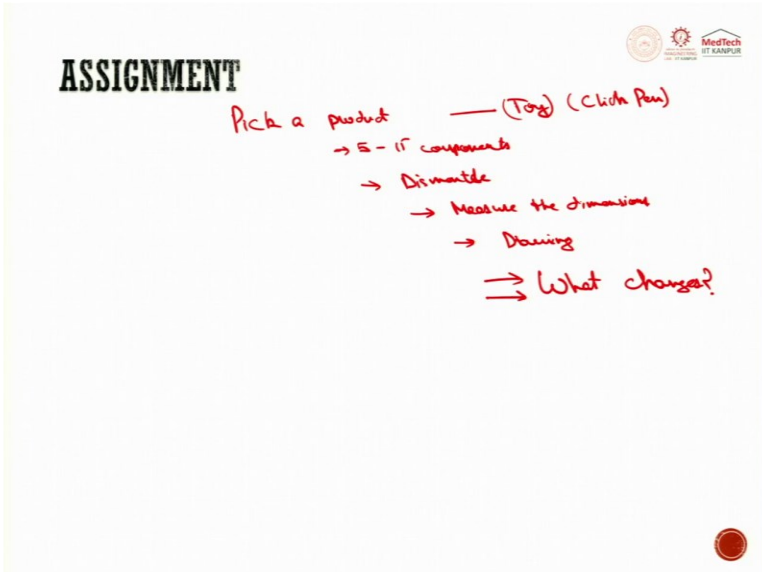

I have a small assignment for you, try to pick a product that is around you with at least 5 to 15 components, try to dismantle it for example, you can pick a toy, you can pick a click pen. If possible, try to measure the dimensions, this is the data that you have recorded.

Obviously, you can make a drawing of it if possible, if you have picked a toy for example, it is a push toy that to how the toy operates or the toy if the toy runs if you put try to push that thin string out of it you can make a drawing or you can just draw roughly the outlines of components which are there, then try to see what changes could you bring in it?

What changes could you bring in it for you so as the pen operates in the same click force in the place of the spring, can you replace the spring with something smaller size of the other push system? Or can you have the click of to suppose the click is at the back? Can you click here or you can clear have a comparison with the pen that is having a side click and the top click, try to have the understanding of these products.

This will give you an understanding when we have tried to dismantle something how the products components that are related to each other and when replacement, what retrofitting, what tinkering could happen there. Definitely, we will have a demonstration in the next lecture where we will try to see the 3D scanning process in detail. Thank you.