CAD / CAM
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Lecture No. # 12
Reverse Engineering

So what we will do in today's lecture is basically take up one of the very important topics related to CAD CAM. The lecture is titled as reverse engineering. So let's look at what exactly is reverse engineering particularly in the context of CAD CAM and how this can be used for rapid product development is the subject of this particular thing. First thing is one should know what is, what one means by reverse engineering.

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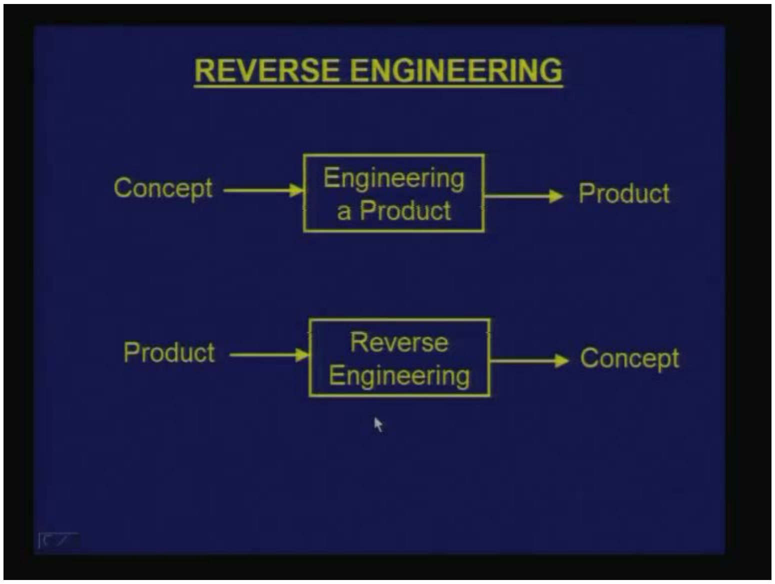

This is one particular term which is used in many areas of engineering, many areas of application. So one of the common ways to understand reverse engineering is first we should know what is engineering a product. Then will be able to know what is reverse engineering. Many a times the term which is used is what is called as a product engineering or you are engineering a new product that's what is often, one of the phrases which is used. This basically means that I have a concept for a new product. I start from a concept, by the time I have fully developed a product which includes its design, manufacturing, process planning, everything. Every aspect of product has been, you can say laid out and complete decisions which are related to product data has been taken.

So this is a long process and often iterative process because you really do not know when you have a new concept for a product, what is the final shape is the product is going to take like it's not something which can be very easily algorithmized and the process is highly iterative. I may come up with product version A which may have certain deficiencies, so I may try to improve it. So finally when you arrive at a successful product, you say that I have engineered this particular project product. So you also find in many of the industries there is a, in fact either they may call as engineering department or sometimes more often the college of product engineering department where new product development concepts are always tried out. So if you look at the reverse engineering, it is like, you are given a product which has been engineered by someone like this is a working product, this is probably a product which is developed successfully. But you would like to know what was the concept like behind this particular product like instead of going from concept to product, you are given a final N product but you are trying to find out what was the intention behind developing this particular product or how the concept has started or you would like to know if the product is a complex what are its sub elements, how these elements are related. Together this system, what is the intended function of this particular system, you try to understand all aspects. So if I move this in the reverse direction this is called as the reverse engineering.

Now sometimes people may like think that what is the need for this. Engineering a product makes sense but what is like if there is already a product, what is the intension behind knowing a concept. Before we take up little more in detail the reverse engineering, let’s look at a certain areas where they are commonly found their application then will come back and look from the CAD CAM point of view like you will find the term being used in software.

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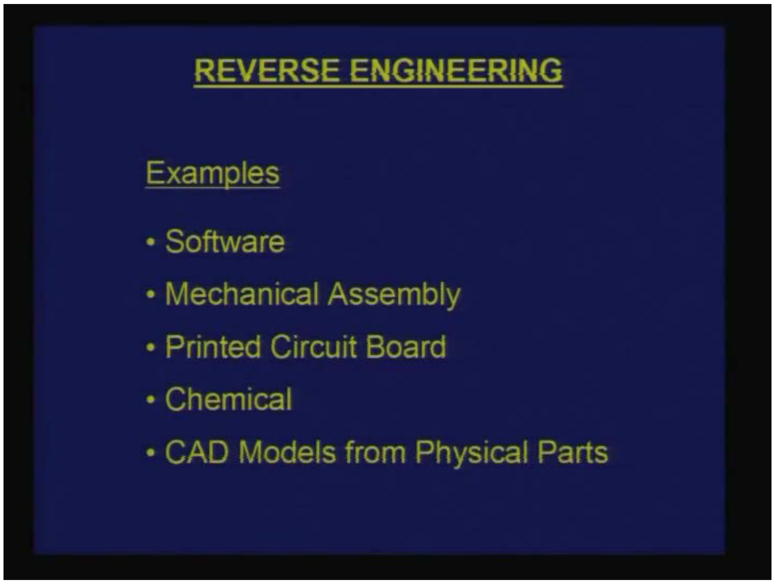

Suppose you write a program. When you write a program, you have certain input in your mind and certain output in your mind. The product is intended to do a certain requirement, take certain input output. Now suddenly somebody gives you, here is a program let’s say 1000 lines scored, can you find out why this program has been written or what is like what exactly this program is doing. You get a code, you really do not know what it is doing. If I am able to like decipher what the program like why the program is written.

The program may be simple multiplication of two matrices or it may be certain operations related to matrices but unless I go through it completely and analyze, do anatomy of this, I won't be able to find out why this particular. So people also do a reverse engineering in a software in which you already have a software product, you are given a software product, you are trying to find out why this software has been developed, what is the intension, what the product does, where the software can be used is one of the application. So this is an example of a reverse engineering or it could be a mechanical assembly like suddenly you find that there is a mechanical assembly which is given to you. You have never seen this particular assembly but it has many parts and a complex kinematics. You would like to know what is the intension of this.

This may be probably like this may be a product which you may have obtained let's say in a war like situation from the enemy's camp. So you would like to know what exactly this particular mechanical assembly intended for, so you try to do that. If I am trying to basically look at what is the system, how it works, what are its dimensions, together what the system is meant for if I am able to find out, I have reverse engineer the mechanical assembly. Sometimes you may get a PCB like so a printed circuit board is meant for certain applications. So you try to find out why this PCB has been developed that's also a reverse engineering or suddenly you may get a chemical, you would like to know what is this particular chemical whether it's an anthrax or it may be something else. So you have to do a reverse engineering of a chemical and when it comes to a CAD CAM application, you are probably looking at in a little more I can say restricted sense which basically means that you have been given a CAD model.

If you know you have been given a physical part which is already been produced at this thing, you are asked to find out a CAD model like in a most of CAD CAM applications what we do is that you start with a CAD model and then realize this particular model by certain manufacturing application. But here in this sense, you are already given an object which is manufactured or which has been built by some inch for which there is no CAD model exist. See you are asked to build a CAD model from an existing physical object. If you do that, that is the reverse engineering in which we would be concentrating that is more of our application. So I have just given only a few representative applications, so it can be used if I take a general definition of reverse engineering, it can be applied to many areas.

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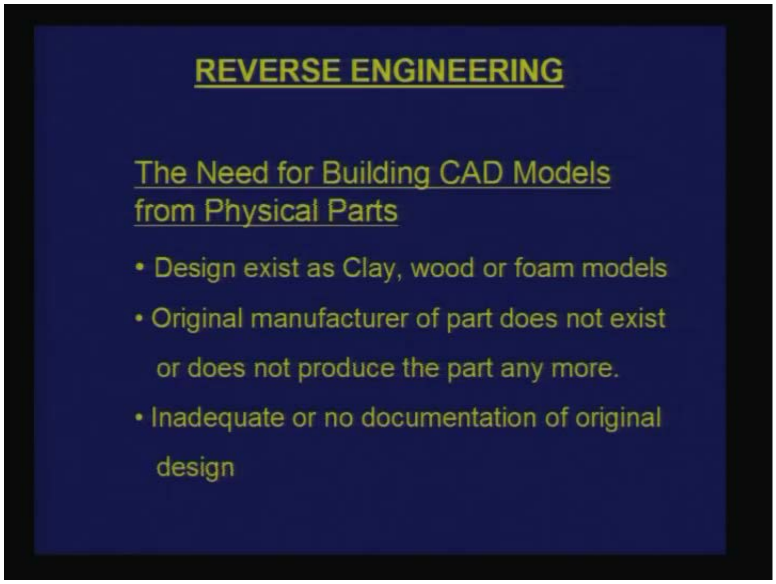

Now why do you need let's say building a CAD model from physical parts like where are the applications or why one has to do this. Now one of the applications is many a times when a new design is demonstrated, it is usually demonstrated as a model which is prepared in either clay or wood or foam or other material. Though lot of developments have taken place in computer aided design, use of CAD tools for design but still there are large number of you can say application areas where people prefer to use let's say clay model to show their let's say new product which they are launching or which they are in the process of development like even for example if I take an example like an automobile where probably that's one area where CAD CAM tools are used extensively but still there are automobile manufacturers, who first make a clay model and show that this is going to be my new model of a car.

And later on probably I will go and build a CAD model for that like many a times when design students are also working like there are specialized design courses. At the end of design they come up with let's say a model in a wood or a clay and show that here is my design. This is more common probably also with people who are in the area of arts like where you come up with new designs, you represent and this is usually made in one of the demonstrated as an example made in a physical part and I would like to go and build a CAD model like you have demonstrated a product which is a clay model and it has been appreciated. Now you want to go for manufacturing that, so you have to capture that geometry may be you would like to modify that geometry a little bit.

So, first step is to convert this physical geometry which is a part of a physical prototype in to a CAD model which is probably the most common application, a building CAD model. This another like area where one finds reverse engineering that is building CAD models from physical parts is that, you have actually bought let's say product long time back. One of the parts has worn out or lost or broken whatever it may be, you would like to replace it.

Now naturally you would like to contact the person who was supplied this particular product and you see that either the person or the organization which has supplied this particular product has closed their shop or they are not manufacturing this class of products any more. So where do you get let’s say spare for this is probably if it is not available in the market then one thing is I may have a worn out part. I can always reverse engineer it. Once I build a CAD model, maybe I’ll manufacture in house by existing manufacturing methods which are available in my shop floor or I can order for this particular component with some other people who can supply this. And this needs for like building a CAD model from the physical part, this is actually true in fact.

Many a times we get like request, people come up with a component say and they request that can you give us dye for this particular component. They don’t have even a drawing for that, all that which they have is the physical object, so that’s like a typical case of reverse engineering. Then sometimes like company which has been manufacturing a particular component or a product has not documented its own product properly but whereas the physical version of the product exist in the designer, it’s already available in the market. So you would like to redocument it. Usually what happens is you have a CAD model which is stored in your computer or let’s say you have a product geometry which is drawn on a drawing sheet. If these two are not available then you have actually lost the documentation for that. So you go and build a documentation again from scratch, so that’s another application.

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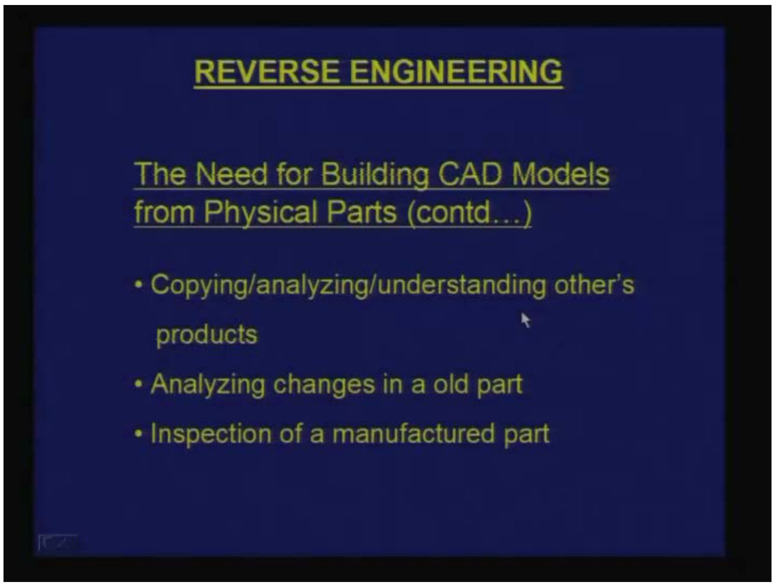

Then it’s also used for copying, analyzing, understating others products particularly the compotators. And of course this has a legal implications too but still there are lot of within certain this legal frame where certain reverse engineering is allowed. You would like to see how the compotator has arrived at a geometry or what kind of configuration. So you would like to reverse engineer and may be, you would like to reverse engineer and modify that geometry to your requirements and then do that. As I said suppose if you get let's say part which is obtained in a war like situation, you would like to also build that particular part and see that. So there can be many situations where you try to copy or analyze or understand the products or components which are manufactured by someone else. Then analyzing changes in an old part, it's like suppose I have a part which has worn out a little bit but I would like to know whether the wear and tear which has taken place in the part is a considerable.

What you do is you have a model for that particular part which is a design model. Then this has been manufactured and in use for quite some time because of wear and tear its geometry has changed. So I'll build a CAD model from this worn out part and then compare with my original model to see that the wear is or the deviation from the intended design geometry is not within certain limits, so that this will continue to work for another few years. This may be done as a part of a maintenance. In maintenance, you need to check certain this thing for wear and tear etc or it may be like you are in fact most, one of the most common applications of building CAD model from physical parts is inspection of the manufactured part like in all manufacturing process the intension is to realize the geometry which has been designed but in most of the manufacturing process, the geometry which you obtain can never be a perfect or it can never match with the design geometry.

Only thing is you try to achieve the intended geometry within certain tolerances. And the deviations are can come from because of many things like it may be because of the defects in the manufacturing resources, machines, etc which are used to manufacture the product or because of the process parameters. For example if I am using let's say at a machine component. The geometry of the machine component may deviate from the actual intended geometry because the machine tool which is used may be imperfect or the machining process conditions are such that either there is a tool has worn out or there is an excessive deflection of tool which has changed the geometry which is there.

So you would like to compare whether this manufactured part is same as the original part. So what is done is after manufacturing, you build a CAD model from the manufacture part. Then you have now two CAD models one which is an original CAD model which was the design one, second one which is obtained for this I can compare these two to know whether it meets the quality requirements or inspection requirements. So that's something which is done in many routine cases or this is something which is probably applied to all engineering or manufacturing organizations where one has to do that. If it is, if the component has let's say features which are like cylindrical features or flat features many times you don't have to reverse engineer.

I can directly measure certain feature, certain dimensions using instruments which are available in metrology lab but suppose if the object is free form. I cannot have let's say either a Vernier or a micrometer or let's say using let's say gauges or other you can say relative measurement tools to ensure that the product geometry or quality requirements are met. So I'll build a CAD model of this particular thing by taking let's say large number of data points on this and then I'll compare this CAD model with the original design model to see whether there are any deviations.

So these are you can say some of the applications which basically is convincing that yes we need reverse engineering in certain areas of application.

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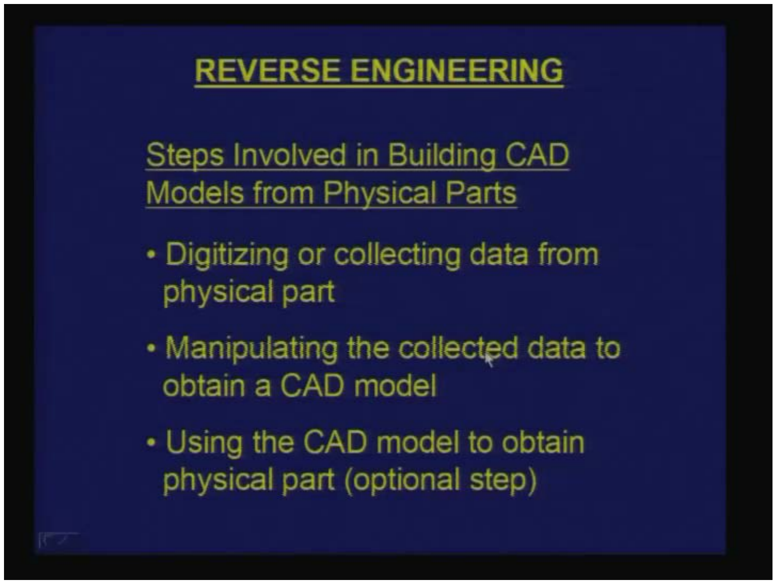

Now what are the different steps which are involved in building let's say a CAD model from physical parts. So, we are now trying to understand the process having understood what is the need for this. In all, most of the cases what you need to do is digitize or collect data from physical part. Now collecting data may be in terms of features that means the part has let's say n number of surfaces. Some of them are flat surfaces, other are cylindrical surfaces, some are spherical surfaces. So I individually build this measure for these surfaces and then try to build an object purely in terms of certain surface features or it may be that I am looking at an object which has a free form geometry, so directly it cannot be captured as one of the known forms of features.

So I collect a large amount of data points on this surface and try to build a CAD model from a large set of data points which is called as a point cloud data. So collect the point cloud data then build a CAD model from point cloud data and then use it for whatever applications which you want. So that is the first step. Then once you collect let's say these data from because of the digitizing or let's say using that, it's not directly in a useable form. Many a times you have to do lot of manipulations with the digitized geometry before it can be used for let's say comparing with the original design or for subsequent manufacturing, will come back to that what are those problems using example. And then once I have building a CAD model from physical parts will be over here but you may not stop there in a reverse engineering situation. The CAD model which has been built will be used subsequently for further manufacture, may be one of the other processes to do that. So this is an optional step which you have in this. So this is the basically a three step process which is building a CAD model from physical parts.

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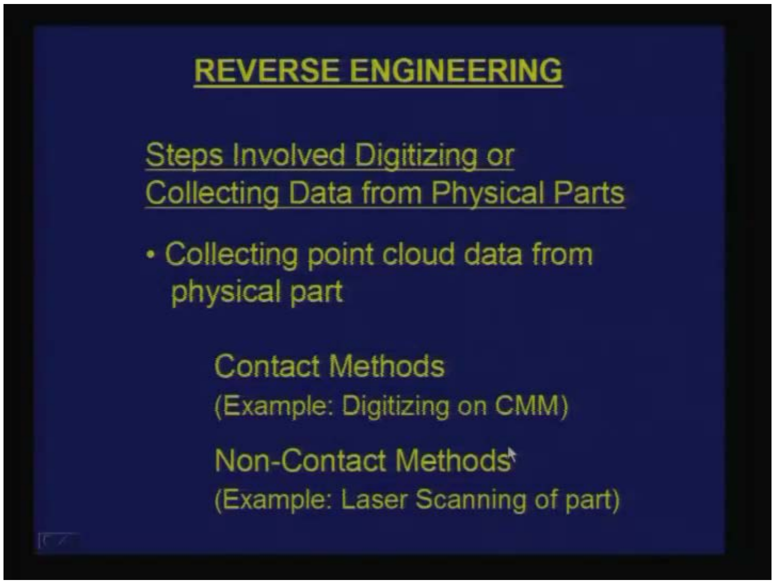

Now here in this context like how do I suppose if I am given a physical part, it has certain features. What kind of methods or what kind of instruments, equipment which I need to use in order to collect its geometry or the geometry features. So there are two most common routes which are available to one. One is I can use contact methods. The geometry of the object is captured by making a contact with the object that means you have to basically touch the object just like as you do in coordinate measuring machine. When a coordinate measuring machine is used for inspecting a part, you have a CMM probe which actually makes contact with the part at a few salient points in order to check its geometric features and dimensions. So that is why you classify this as a contact method.

One can also look at non-contact methods. In non-contact methods what you use is like I can use for example let's say a laser, a laser beam to capture the geometry. People also use like scanners which are based on white light to do that which are often called as a 3 D scanner. In some of the situations what is done is suppose if I want to capture geometry of this, I can place this in a stand. And then I have like geometry of this is captured from various angles and I build a CAD model from that or in another option, you keep this in a rotary table and then the rotary table is made to rotate by one complete revolution. So you are also capturing this particular geometry, if it is not axisymmetric or something else.

So there can be a many ways, when I am using let's say optical methods or sometimes you use a methods which are based on tomography. You are actually not touching the object but basically you are using a non-contact method to do that. Both methods are equally popular in industry for reverse engineering. I can either use a CMM or also use a laser scanning or white light scanner to do this like let's take the first aspect suppose if I am using let's say a coordinate measuring machine, a CMM for collecting the data points.

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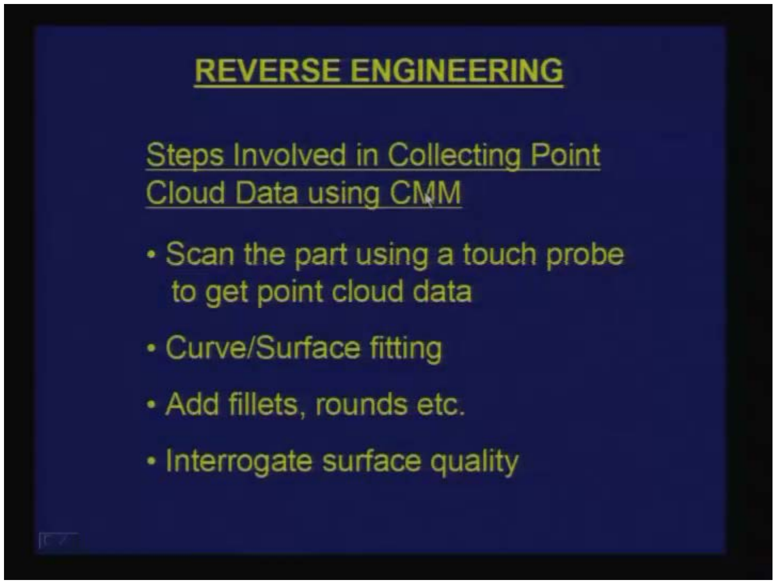

So you scan the part using a touch probe which is the part of a CMM system to get a point cloud data. Now we are calling it as a point cloud data here, the assumption here is that you are looking at a surface which is like a free form. I thing one of the good examples is a mouse like suppose if I want to capture a geometry of this, I cannot really say that all its surfaces are known form that it’s like it has flat surfaces, cylindrical surfaces or spherical. I may have a certain free form surfaces too. So I would like to basically take a number of points in order to capture the geometry with which this mouse is made up of.

So once you get a large of number of points which are related to this particular surface then you need to actually fit curves and surfaces in order to build the geometry. You cannot directly go from point to solid in many cases, you may have to build from zero level point to a curve, curve to surface, surface to a solid, it could be one of the options. So what is done is like this may have number of surfaces. I may take number of points on one surface, many points on the side surfaces. So you have an individual features which have been scanned. I also have to assemble these features to make it a complete model of that but like for example if I have two surfaces one which is a curved and a flat surface, they are also intersecting at some point. It’s not possible to take exactly points at those intersections.

So I need to sometimes do surface, surface intersection calculations or if I have two surfaces I have to blend them with a smooth radius or if there are gaps between that I have to basically see that the contact has been made between these two surfaces with no gaps which is called as a stitching in CAD terminology. So I have to stitch pieces of surfaces which are available to you. So, all these is a part of a second step. Collecting a point cloud data is a part which you do with the equipment, a coordinate measuring machine. Then you come to a processing of that on a computer where you take a point cloud data as input and get curve and surfaces to this.

As I said you need to do certain manipulation in order to do this like if you have a gaps etc those have to be filled proper, blending has to be there. The object may not really have a sharp corner but when I have two surfaces which I am trying to find intersection, I'll always get a curved or a sharp edge but actually it has a small fillet radii. So I would like to provide that fillet radii which is there. And you also interrogate about surface quality whether how good this fitting has been, whether the surfaces which we have constructed from point cloud data itself has a large error or it truly represent the point cloud data.

And whether there are any gaps or interrogation also includes finding higher levels like slope continuities, curvature continuities of the surface whether they are met or not. All those things are done as a part of this. So this aspect is usually is something where lot of experience is required, the people who have been doing this kind of reverse engineering. And there are also commercial software which are available which can be used to do this. High end CAD CAM systems can be used but there are some specialized reverse engineering software which can give you many conveniences to do this kind of manipulation which is required after the point cloud data has been obtained and curves and surface have been fit for those aspects.

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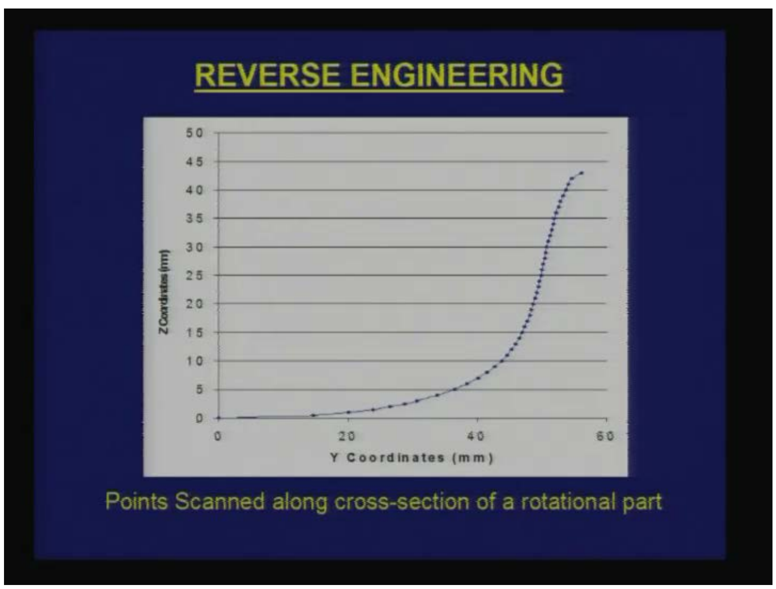

I'll just show you may be one or two examples which will demonstrate like here is an example of a part which is axisymmetric. This is like an object which is in the form of a bowl but since it is axisymmetric, I don't have to take points all along it's this thing, because it is some same cross section which when revolved has been obtained as an axisymmetric part. So even if I take let's say the measurement along the section, one of the sections that is enough. So what it shows here is like you have a number of points which have been obtained on a CMM and then there is a curve which has been fit about this. Now I am going to revolve this particular curve to get this thing. So this is actually the data which is obtained on a CMM what you trying to see.

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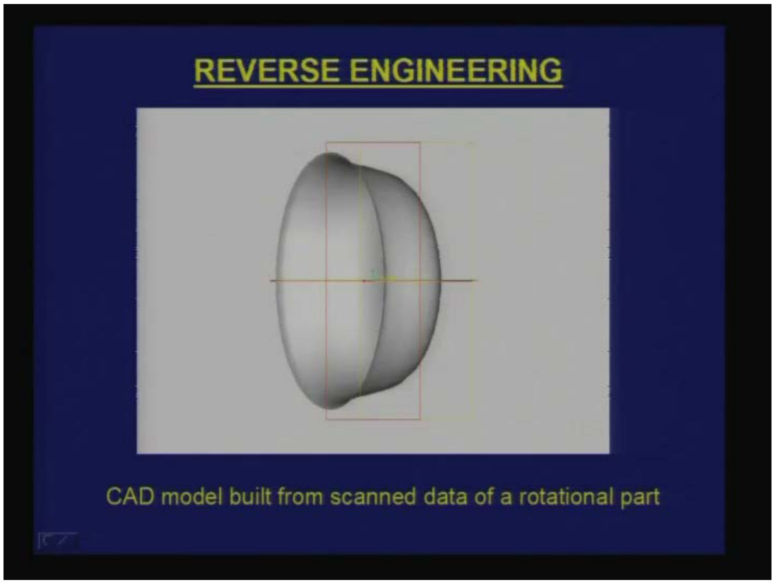

Now when I revolve it, fit the cross section, I have obtained a CAD model from a physical part. Point cloud data was obtained from a physical object. Then you build a CAD model using this. Now suppose I may have a further applications like I would like to have two dyehalf for this particular component then once I have this geometry, I can go and do that.

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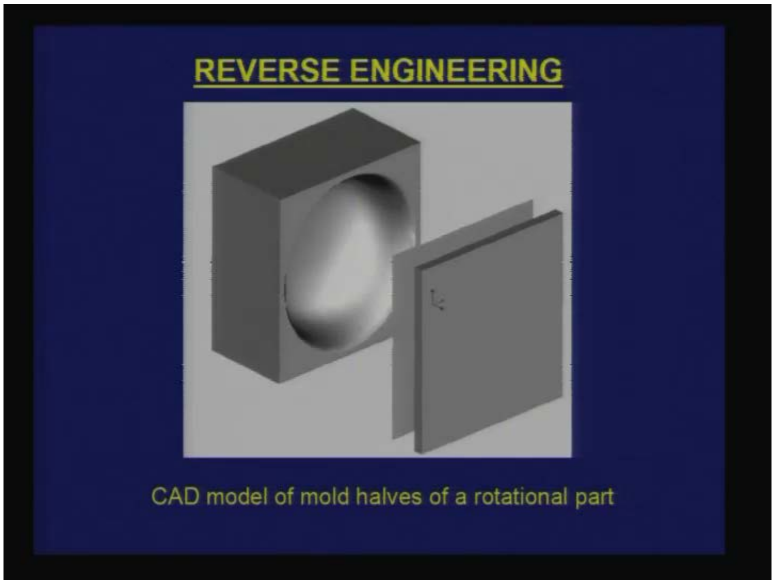

For example that's a component for which I would like to also have a dyehalf, let's say I am carrying out an operations like may be a sheet metal forming where I would like to reproduce that particular part, so I can also go and build this particular.

So you had a physical part then you took the point data, fit a curve. This is a very simple example no surface fitting. It's only a curve fitting and then revolving to get a surface and then using the surface definition you are able to build let's say mold. Now I can manufacture this mold and go and make any number of those parts which are available to you. Here is an example, this is actually a machined part.

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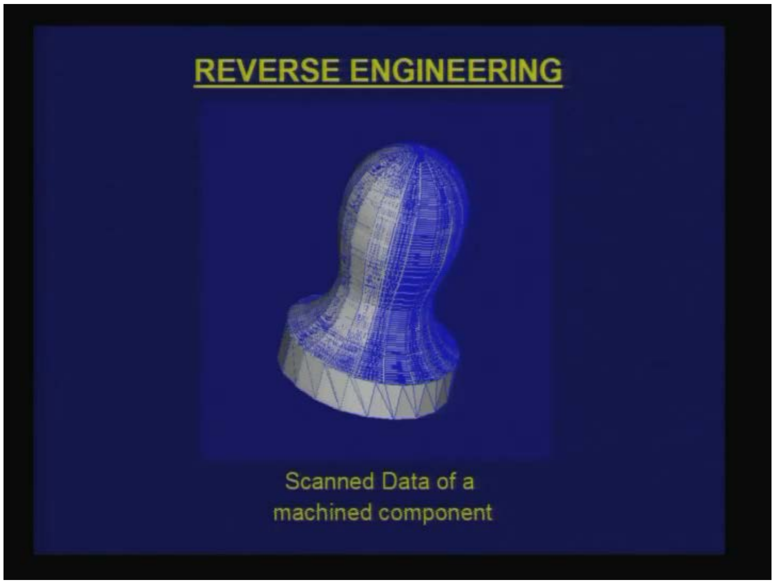

A part which has already been machined and number of points have been taken and one of the waste to let's say a fit surfaces for a point cloud data is also using only triangles. If I have large number of data points which are obtained, I can fit let's say a triangles to get an approximate surface for this particular thing like this is like representation is more like an STL. Suppose if this has to be manufactured by rapid prototyping that's convenient or I can also use this. There are special NC program generation methods which take either input as directly point cloud data or an object which is represented only as triangles, this is possible. So in those situations I can directly use this. So this is the actual you can say the data which has been scanned and obtained from the physical part and the part which has been reconstructed is here.

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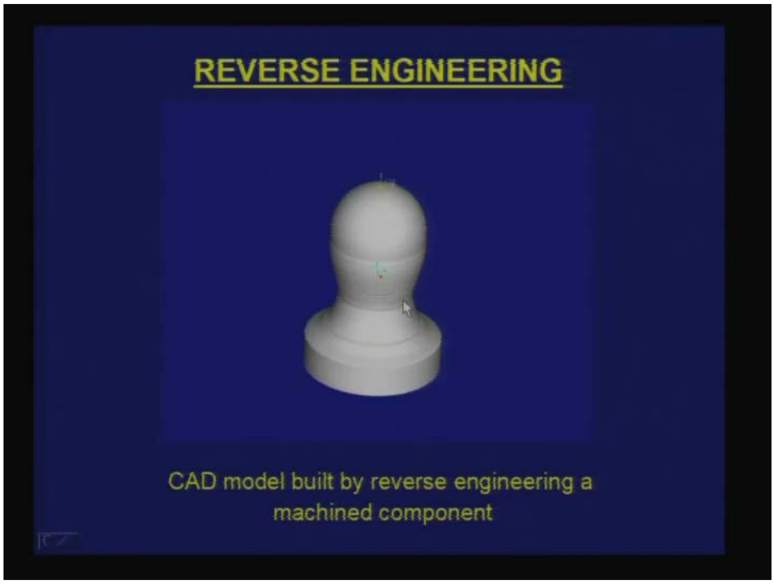

And an interesting thing which you see here is that if I take enough data points. I can even get those marks which are obtained by like the parts, when this part was machined you also have the marks which are left by the cutting tool. That is the texture of this particular part. You are able to capture that because you have taken enough number of points to fit this kind of surface. So this is actually a CAD model which is built from a component which has been manufactured. And that gives basically like this may be. Now I can use this compared with the CAD model and see whether this particular contour which is critical to me, whether it is being satisfied or not. Here is another example.

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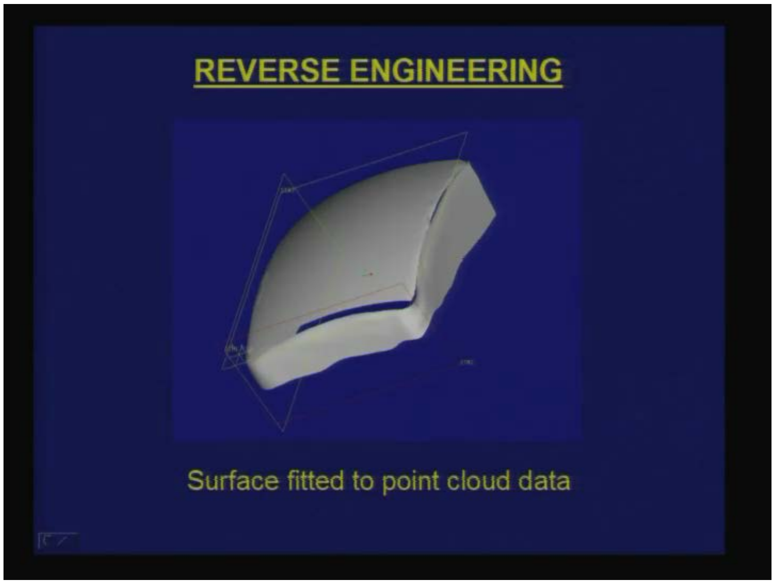

In fact this is an example of a surface which looks more like a mouse kind of a thing. So when the point cloud data has been taken in terms of pieces and once it is built, you see that there are gaps because they were not many points which were taken in this, the surface could not be a complete. Now this is not a very valid surface for me. Usually what you would like to obtain in most of the situation is what is called as a water tight surface. There should not be any gaps between this particular thing that means if you have any gap that means water will pass through. So once you do a reverse engineering that is build a surface. Now I need to do some stitching operations and do some blending operation in order to fill this which can be done either in a high end CAD CAM systems with lot of effort or using a specialized reverse engineering software where this can be easily done. And finally I come up with let's say a geometry which is, which meets my requirements which has proper blends and others.

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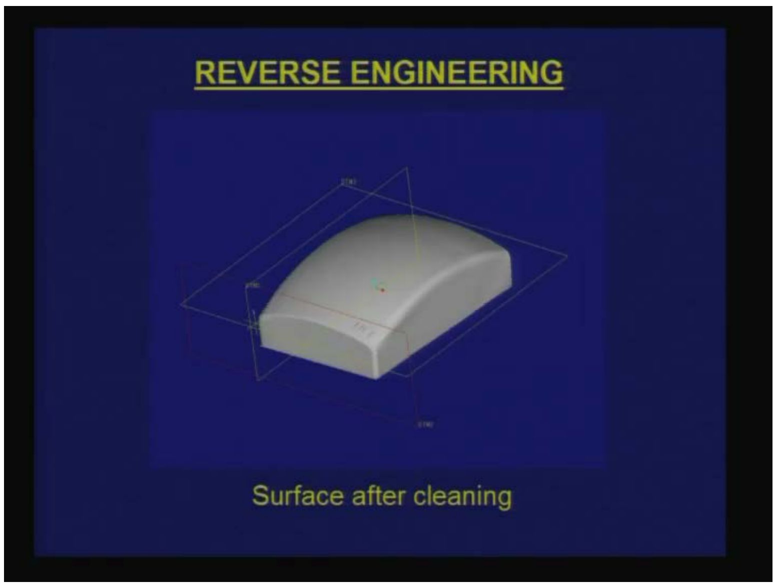

I can probably go and use this geometry instead of using that. So fitting a surface to point cloud data is many a times nontrivial process. As one has to spend lot of time in order to see that the kind of geometry which is obtained really meets once requirements. Then if I am going through a contact method, I am getting a lot of point cloud data and we do that. Suppose if I am using let's say a non-contact method where either a white light scanner or a laser scanning is done. It's slightly different from that. Usually in a process like this, the amount of data which can be obtained is enormous like in a very short time, I can get a large amount of data compared to a coordinate measuring machine where your probe has to basically scan the entire surface to get large number of data points. So there is a time factor which comes in the case of a CMM. And also whenever you have a discontinuity, probably probe cannot reach those discontinuities, so you may have certain data which may be lost also.

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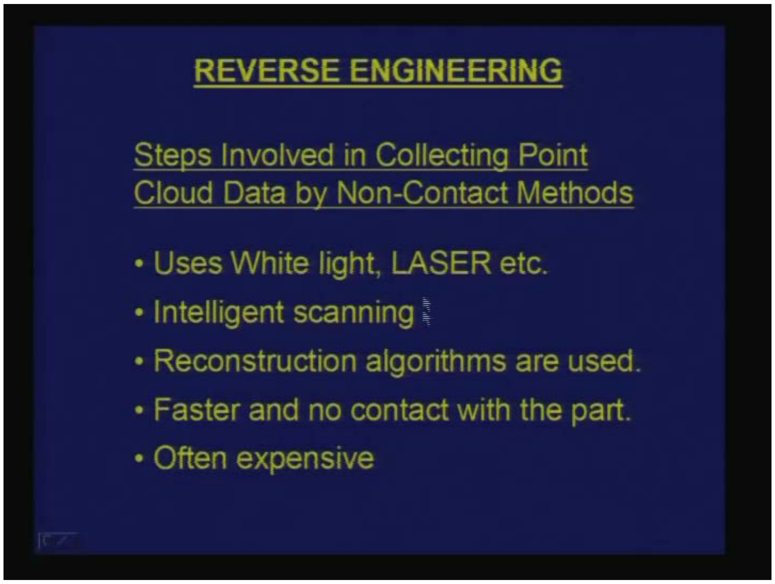

Here one thing is you can get a large amount of a data that is first thing and one can also do an intelligent scanning. An intelligent scanning means like suppose if I have let's say scanning along certain cross section, if I take let's say points which are located at certain distance. Then suppose if I am taking let's say 10 points which are equally distributed, I may have a problem.

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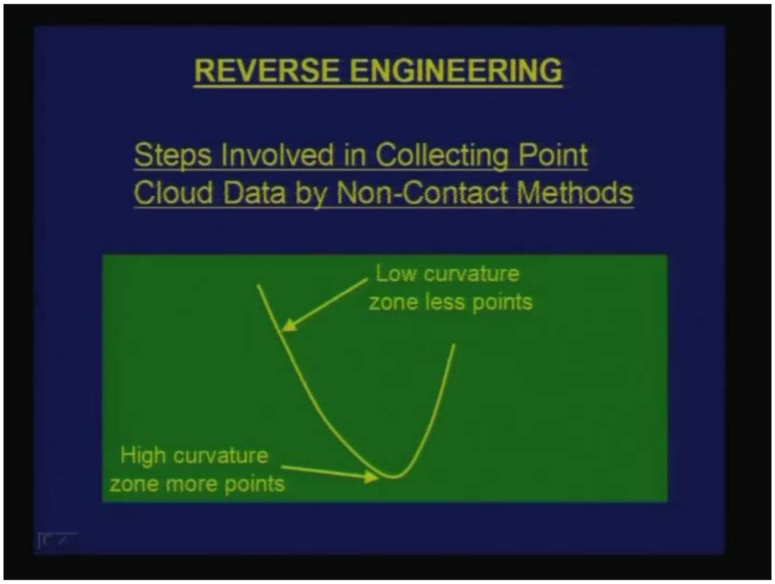

The problem comes in those regions where there are high curvature. I would like to have a very high density of points in this region. So as your scanning you are also trying to find out how the curvature is varying, if you have reached let's say a zone where there is a high curvature zone, the number of points which you take will automatically you would try to increase the density of points in that particular region. So this can be a part of the software which is actually driving the scanner to collect the data points. So this is possible in intelligent scanning but if you are doing with CMM then manually you have to see that there are high curvature region, so you go slower or you collect more data points which has to be done. But here the previous data points will tell you that how, what has been the rate of change of curvature or slope and I can do that.

So I can do an intelligent scanning and one has to again reconstruct the, let's say a CAD model from the data points which are collected. As I said the method is faster and there is no contact. Sometimes you may have an object which are highly flexible. They have a very high flexibility that any contact which is made will deflect considerably. So in those situations probably non-contact methods are found to be have an advantage. And often the method is expensive because these scanners are quite expensive. As if I want a good resolution or accuracy in terms of scanning then one has to spend lot of money in order to buy these scanners. So this basically shows that you can do some intelligent scanning but one important aspect in many of the scanning by non-contact methods is that you may have to use sometimes a different algorithms to basically get the surface model.

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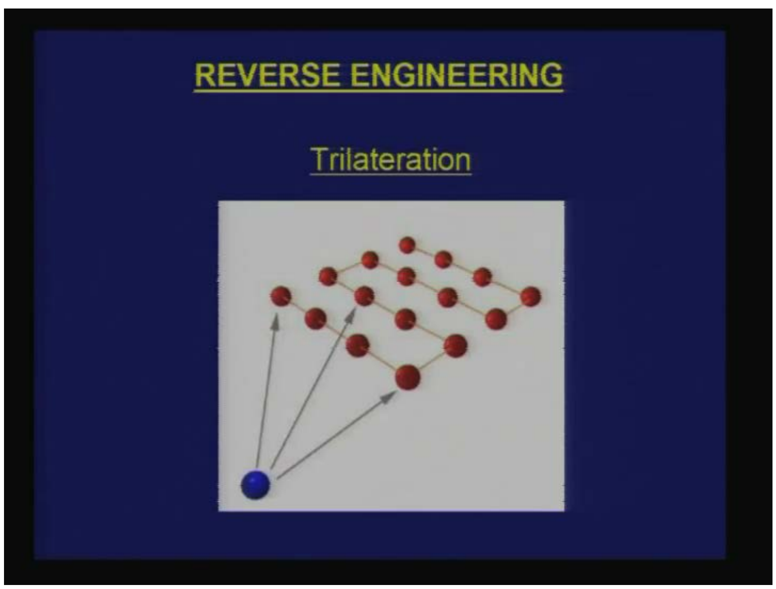

In fact one of the common aspect is called as a trilateration. In trilateration what is done is suppose here is a source which is basically a source which is scanning the object. These are the point data which has been collected. You may not really get XYZ positions of these points that means those are not the once which can be, which has been captured by a scanner. What the scanner could capture is only a distance of this particular point from here. So, it is like, you know all these points and their distances from this, from the distance data you should be able to get the like get the physical object. So this require sometimes an additional processing and this is usually called as a trilateration process or trilateration algorithms. This kind of things are not, trilateration is something which is not common to only this, it is also done in like civil engineering applications like surveying.

When I am doing a surveying, I get lot of data on the terrain which are all distance data. From large set of distance datas, I can find out what is the relative you can say location of the points and I can fit a surface using this particular thing. This is something which usually is taken care by the software which is applied with the scanner. So one may get actually a point cloud data but trilateration may be a part of this scanning process in some cases. And it also depends on how good is your trilateration algorithm, there is some accuracy which is lost in the process too. and trilateration is also, one of the other aspects how computationally intensive because as the cloud data increases the number of points, there is a time which is involved in the whole process of this, getting the data points and using this. Then coming back to the third step that means after I have build, let’s say CAD model what is the intended application of this.

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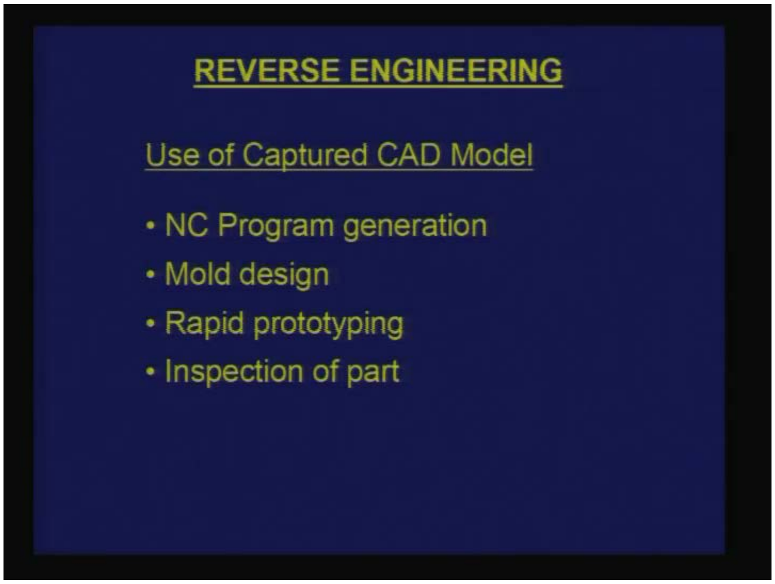

One is like we have discussed that I can compare the part which has been scanned and whose CAD model has been built is compared with the original CAD models, so your application is purely inspection. But many a times in reverse engineering, I start with the physical object and at the same time I would like to end with another physical object like this may be made of clay but I would like a metallic part of that or I may require a plastic part of that. I may require either one in number or thousands in number, so depending on the route you have a various applications.

For example let’s say if I want a few parts of that, I already have a CAD model. I can take this CAD model to a CAM software where I can use the geometry to generate the NC tool path, generate the part program, take it to machine and cut the part. If I want 1, 2, 5 or 50, I can cut any number of parts which are possible. But suppose if this component is needed in large quantities let’s say you intent to manufacture the geometry which has been captured by a process like injection molding or die casting then you go and build a mold for it so that I can get the components which are a few tens of thousands or millions in number or I may require just one another part like in fact there are many situations where a plastic part has been worn out.

This has been reverse engineered. After reverse engineered you have the geometry which is the worn out geometry but you are able to correct it to get the intended geometry and I can just want one more part in a process like a rapid prototyping and just replace this part with the existing part. So you are just looking for may be one or two parts which are needed for this, so it can be send to a rapid prototyping. So there can be many routes after CAD model has been obtained or it could be an inspection of part as we have seen that. There could be other applications but these are the more common end applications which one finds in this. Yeah, when it comes to an inspection, here we also have an important aspect is what is called as a part localization.

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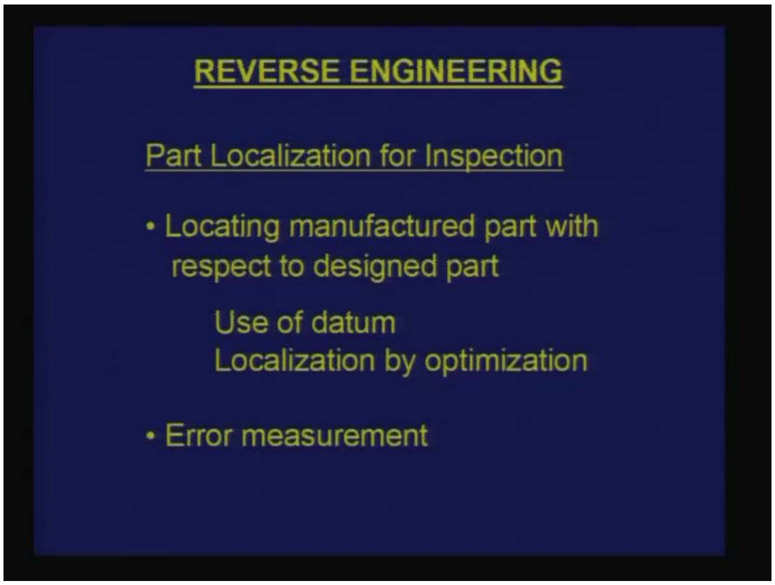

What is done is once I have let's say captured the CAD model which is, which has been built in a CAD system or using a reverse engineering software. In order to inspect I have to compare this with the design geometry which is there, so I need to, how do I do this particular comparison because these are two different CAD models using two different you can say coordinate systems in which their data has been obtained. But I would like to basically compare them, let's say to know whether the manufactured geometry really needs the designed geometry. So there are two approaches, one is I have a datum which is there for the design part and I am also able to obtain the same datum for manufactured part. So if these two datum's can be matched that means I have a CAD model of the design part, I have the manufactured model.

Manufacture model is located with respect to the design part in the space such that the datum planes or datum directions or datum surfaces match. Once they match then you do the inspection and you say that how much is the deviation or error which is possible but there are many situations where the datum cannot be obtained easily like if I take a situation like a component which is machined, usually you have a certain flat surfaces or cylindrical surfaces which can be used as a datum like if I am using a process, if I am using a manufacturing process where datum's cannot be obtained like if I take an example of let's say a part which is manufactured by investment casting. So, since this is, it's not a machine component. It is obtained directly from let's say manufactured geometry. It may not have any datum surfaces like a may be a turbine blade which is manufactured using investment casting may not have really datum planes. So that I can match this with the intended geometry.

So, what you need to do is that you basically after the solid model has been obtained from the point cloud data, you try to localize one with respect to other by carrying out an optimization process. I have an object what should be the like basically transformation which should be applied to a manufactured geometry, such that you say that one has localized with respect to other that means one has been placed where the error has been between the two parts has been minimum.

So, once I do a localization then I can actually go and measure the errors and say based on his particular localization process, whether the manufactured object really meets the design requirements. That means it matches with the design geometry within certain tolerances or not can be checked as a part of this particular aspect. This is like, you can say a final application of this. So this is in brief about what I basically wanted to cover as a part of reverse engineering. Otherwise nowadays reverse engineering has become a very common tool in many of the industries, particularly lot of automobile industries come up with request for reverse engineering products etc which is very common.

And there are also what you call as a mobile hand scanners, it's like instead of using a CMM, taking a part to let's say a CMM machine to get the point cloud data, I can also have a mobile scanner. So, I can take the mobile scanner to a place which may be either optical scanner or it may be a contact method. So, I have a part which is a large part and I have a probe, so I will manually probe the points on this particular object and basically get the point cloud data and then process it using computer and do that. So, the benefits of reverse engineering has been that the total time which is involved in product development time could be reduced considerably in many cases. So because of this, it is getting more and more popular as a part of as you can say an important tool for this.

In fact when it is combined with other technology that is rapid prototyping, it is found to be like even more beneficial aspect like one of the, like one of the applications which has been tried particularly with rapid prototyping and reversing, there are many. In fact one application which I want to quote is medical applications. Suppose if I want to replace a missing tooth, suppose you go to a dentist, so dentist has to basically prepare an artificial tooth for that. For that they have to capture the geometry because this tooth has to fit very well with the adjacent teeth. So how do you capture this geometry and the idea is I can use let's say a scanning method to get the cavity geometry. I can built let's say a CAD model from that so you have, the tooth which you are going to build, you already have a

CAD model by carrying out a small non-contact inspection and even people are able to build the tooth using the rapid prototyping like usually if you want to build an artificial tooth this is again like a process is more like a casting.

You have to first make a mold for that and then pour the material which this tooth is made up of and then you obtain the cast part which is actually becomes your artificial tooth. In fact it's a multi-step process. So many of the tooling which is required for let's say preparation of a tooth can be manufactured using a rapid prototyping. And the idea of using these reverse engineering and rapid prototyping is that the geometry is quite complex. The tooth geometry is not very simple. It's quite complex geometry. So, one is able to reduce let's say a tooth replacement time considerably compare to the conventional methods and probably that's going to come in a big way in future. So there are number of such applications where reverse engineering is combined with rapid prototyping to shorten the product development time considerably.

I will stop it here, if you have any questions you can ask or any aspect of reverse engineering which you could not get a clear idea. I think a best way to learn reverse engineering is to basically go through a one complete cycle like in a situation like practical, if you have both CMM NC machine and let's say high end CAD system. You take a part, first scan it on CMM or this thing. Get a CAD model, do all the manipulation and others, then generate NC program for that, cut part bring the part and then compare do the localization and see. So it's like one complete, you can say a cycle of reverse engineering which basically teaches many things, how to scan an object then how to get the point cloud data, how to transfer point cloud data from let's say CMM to a CAD system.

Then what kind of surfaces to choose, of course in most of the fitting of the point cloud data people prefer to use the NURBS surface has one of the standards. So I basically fit NURBS patches and build the geometry. Then I'll take this to a manufacturing software, may be generate an NC program to cut a similar part, take it to NC machine, cut the part then you have obtain the manufactured part which is this particular thing. Now you can basically either I can again scan it, get the manufactured geometry and compare with let's say intended geometry.

So you have completed one cycle and this kind of practical exercise can be done in typically like an investment of about 20 hours, 25 hours of practical work which is… So if there are no questions I'll… Yeah, please. Student: What are the legal boundaries for teaching reverse engineering because this is the copying operation. What are the legal boundaries? what are the legal issues in copying let's say a particular product. This thing is like usually what happens is whenever somebody comes up with a new product, either the idea is patented or it is copyrighted, so in those situations you cannot really copy without the permission of the person who has done it. So, basically like if you are doing that even when it is copyrighted or let's say a patented aspect then there is a problem like somebody may come up with totally a new geometry for a tooth brush handle and they have patented this geometry because it's ergonomically very convenient.

Now the idea is if I want to manufacture like I want to go for this, I can reverse engineer and manufacture my own tooth brush but there may be a certain legal issues which are involved and so that has to be respected, intellectual property rights related issues have to be respected. But in spite of that there are many cases where people reverse engineer is without any this particular thing. So those are situations which should be avoided. But I think in some cases the reverse engineering is allowed legally in the sense if you are, basically if your manufacturer allows you to reverse engineer or there is a situation where this part cannot be obtained without reverse engineering. So there are some issues related to that. It’s not I don’t think there is any specific consortium which is looking at what can be reverse engineer. But this is generally discuss in a frame work of any copyright act or intellectual property right acts.

Shape interrogation basically says that like for example I have number of surfaces patches which have been obtained by fitting a surface to a point cloud data. Now this is not one continuous surface, this is available as pieces. Now I have manipulated them to obtain a one closed boundary. Then you realize that you are able to get one closed boundary but in my finally design I really want a geometry where three is a C_2 continuity. But you are, after you are fitting this particular thing you see that it has not even, it has there is no C_0 continuity like if you have seen the gaps or if I fill the gaps probably, I can overcome the C_0 continuity water tight joints but there is no slope continuity. Even if I get a slope continuity I may not get a curvature continuity. So you need to or it may be reverse actual product has a very sharp edge.

It has really a discontinuity where there is no slope continuity, there is a real slope discontinuity which exists but you are able to get a geometry which is smooth and continuous even that is not this thing. So you try to look at what is the intended geometry and then interrogate that means you find out the curvature at all the points like you basically look at the intrinsic properties of the surface which is obtained and see whether it is meeting that or not. So basically refers to those interrogations with its… So will stop it here and then will take up another application of CAD CAM in our next class.