Higher Surveying
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Module – 06
Photogrammetry
Lecture - 22
Close range photogrammetry

Hello everyone, welcome back in the course on Higher Surveying. And, we are in module 6 photogrammetry. Photogrammetry has been stretching as a lot, do not worry this is the last lecture and it is lecture 8 called Close range photogrammetry.

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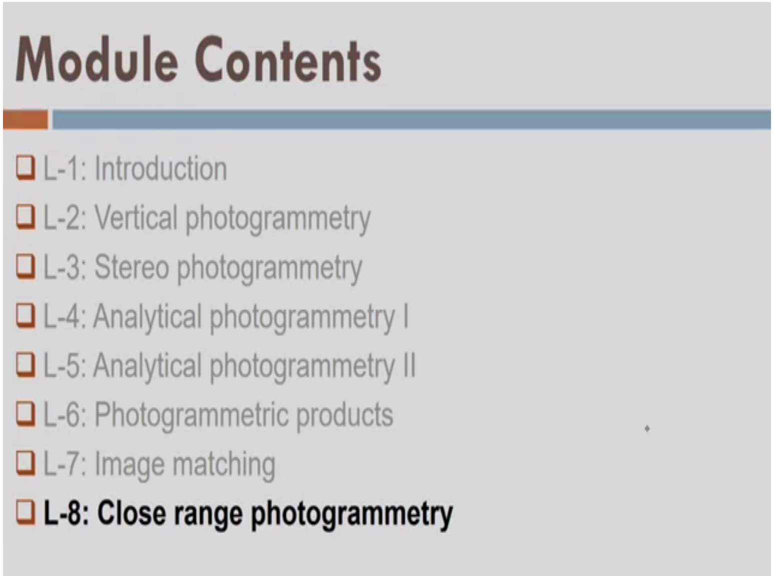

What do you mean by close range photogrammetry? Let us start with that ok. In order to understand the close range photogrammetry, let us understand the far range photogrammetry first. Remember we have mounted the camera in aircraft or we are mounted the camera in satellite right.

In those 2 cases the distance between the object and the sensor the camera was almost in order of some meters or I can say in case of aircraft mounted camera, the distance was almost in range of 500 meter to 15000 meter; that means, 500 meter to 1.5 kilo meters. In case of satellite bond cameras, the distance between the camera and the surface of earth the distance was almost in order of 700 to 1000 kilo meters well. So, we have realized that both are different and it has some systematic corrections. For example, in case of aerial photography we know that there are some type of systematic corrections we have done it right.

So, now what is a close range photogrammetry? Is it a kind of contrast to the far range photogrammetry and since we do not use the word far range photogrammetry. Perhaps the reason could be the far range photogrammetry came earlier and it is started with the name called photogrammetry. So, the later when the close range photogrammetry came people started using the term close range and photogrammetry; that means the photogrammetry and the close range photogrammetry ok.

So, what is the close range photogrammetry? What do you mean by that? As per the textbook definition the close range photogrammetry means, the distance between camera and the object is limited to 100 meter maximum. And so, we say that if the distance between the camera and sensor is within 100 meter, it would be 25 meter, 8 meter, 10 meter or may be it maximum 100 meters. In that case we say it is a close range photogrammetry ok.

So, in what cases it is there? Say, I have an camera and I am doing some kind of photography and I am doing some kind of work where I can want to develop some 3 D model of some building; for example, Taj Mahal, or some hotel, or maybe the university campus or maybe the library of your institute. So, in that case the distance available to me for the photography using a camera is very limited. Maybe 25 meter, 30 meter, 8 meter something like this or if I use a drone, in that case the distance is again very limited.

Generally drone flies up to some level, but let us say it is flying very close to the building. In that case again the distance is very very limited, very small or if I use blimp or any other low altitude platform like drone. For example, kite, pole, blimp, balloon right. In all cases the distance between the camera and the object is very very small much less than 100 meters.

So, all these things came into the you know category of close range photogrammetry. So, today we are going to learn about the close range photogrammetry, because today it is very much important. Let us imagine a situation; you are going on a route. And, you are in a traffic and their you find there was some accident.

And you want to do the 3 D modeling of that accident, you have a mobile camera with you immediately you took the stereoscopic photograph, and using those stereoscopic photograph you want to develop your 3 D view of the accident scene. And so, that you can present it to someone or you may presented, it to some authorities well that is a one way to look at it, imagine that you are and 3 D architect. And some hotel industry or some maybe you know mall industry have invited you to develop our kind of you know develop a excellent 3 D model of the mall or maybe the a building. Let us say an architectural building or let us say some kind of cultural building.

So, in that case what will you do you will go to the place and you will try to go around the place and try to acquire the stereoscopic photographs. And, using those stereoscopic photographs you want to do the complete measurement of that 3 D building for the purpose of measurement as well as for the purpose of visualization ok. What do you mean by visualization? You want to present that model in a computer also to someone also to show on the you know some screen or you want to print a calendar. So, for that purpose you need those things exactly. Moreover, one more application could be suppose you have a mobile phone and in a mobile phone we have the maps now, the navigation application remember we have already used it or we have already referred it in some of the module before.

So, let us say that in that case of mobile map you want to place the 3 D models of the you know good monuments of the city. So, that some tourist comes they should be able to use that; that means, in order to navigate to that place that moment that place comes you know some kind of 3 D model should appearing your mobile phone. So, there also you can develop it. So, all this work come in the category of close range photogrammetry and today we are going to learn about that.

So, what are the important things which are different from the photogrammetry we are going to talk about that. So, by the way what are the fundamental advantages of the close range photogrammetry that it offers compared to other photogrammetry. First is that the distance is limited. So, the corrections like atmospheric refraction is not there rather we can assume that the line of sight we should refract over a large distance will not refract it is very straight line, or even if we assumed that it is refracting and if I am taking care of that in my model, what will happen. I can do that accurate most accurate measurements in terms of pixels millimeter level accuracy I can achieve, and that is the purpose of close range photogrammetry.

Even you can develop some maps 3 D maps using close range photogrammetry today. One more advantage, generally we have some cameras which are less expensive right all that non metric cameras because their focal length as well as principle point coordinates are not known. That is the interior orientation parameters of the camera is not known and as a results they are non-metric camera.

Now, imagine that your mobile camera, you have pointed shoot camera, we have a DSLR camera or we have a drone camera, which ever camera we have all are non-metric cameras and now you want to use that in a develop a 3 D map of a you know excellently accurate 3 D and high resonant 3 D map for building can you do it. So, how will you find out your interior orientation parameter?

And for that purpose the close range photogrammetry has some special provision, that first we need to understand what is the camera calibration? The moment we understand the camera calibration we can develop 3 D models very fast, very accurate 3 D models. And, naturally because of the small distance between the camera and the object resolution is very very high. So, now you can achieve the highly accurate 3 D models of high resolution not interesting ok. Let us look into that today ok. So, these are the books again.

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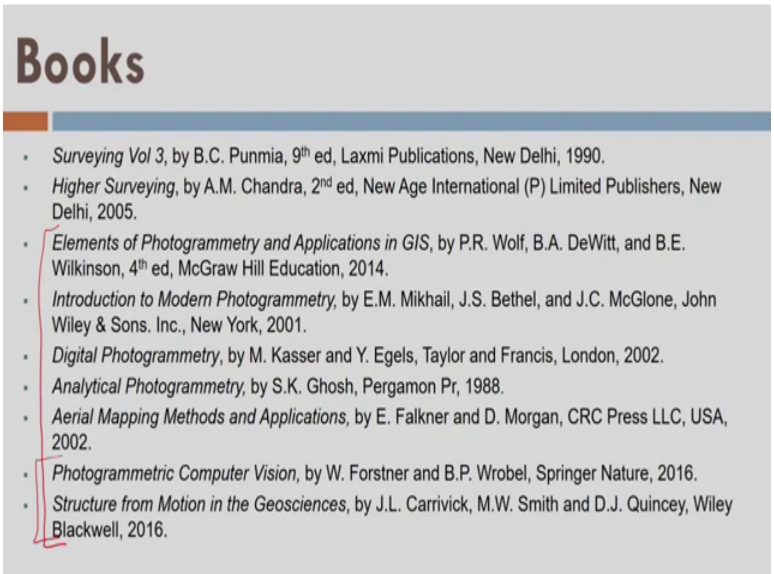

And here I would like to recommend you all the books and, but especially these 2 books are very very special. Again books are very very expensive please go to some library to refer this books ok.

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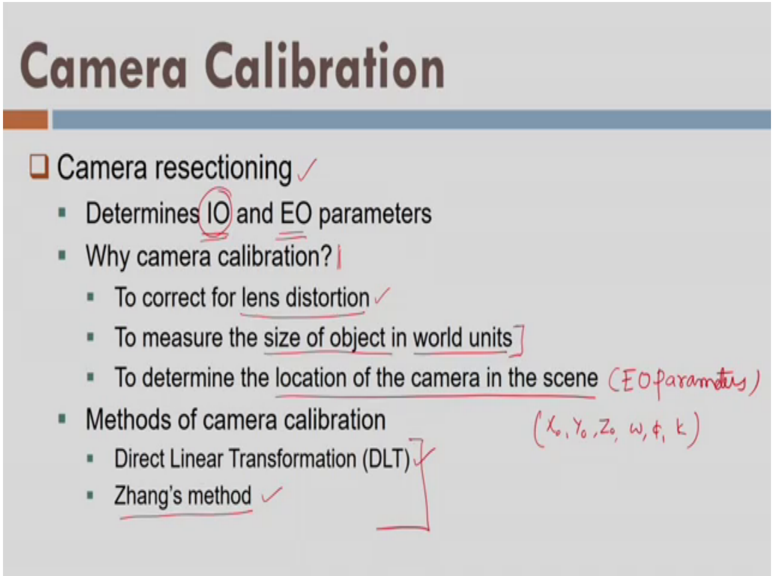

So, the camera calibration as we have already talked is all about finding out the interior orientation parameter of the camera. Now so, I want to determine I O parameter basically; however, in a whole process we also determine their E O parameter.

Let us imagine that I have a camera and I am taking 1 photograph, then I am taking stereoscopic view or the overlapping photographs. Now, what will happen here is let us say I have a mobile phone, and I took 1 photograph here or maybe I could take the photograph like this.

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So, this is the orientation of my sensor or image that is changing fine. At the same time what is the focal length of this camera or the principal point of this camera that I do not know. So, the moment we determine these 2 I can find out the 3 D coordinates of each and every pixel in my image right, and that is the process we do the camera calibration it is also call camera re-sectioning right ok.

So, why we do the camera calibration? First of all the movement we determine the interior orientation parameters, we will find out lens distortions also ok. The moment we find out all the parameters I O and E O parameters then we can find out the size of the object in world units ok. Regarding the world units if I know that what my one pixel is representing on the surface of object, I can always find out what is the size of the building or what is the length of the building, what is the height of the building, what is the width of the building, what is the length of the curve and everything?

That is a idea here; that means, that is what we call the world unit. However, even if I do not know that what is the size of the 1 pixel on object surface, even I can do something that in terms of pixels I can find out what is the length of the road, or what is the length of the building, or what is the you know length of the curve of a railing of a building. Right so, you can understand this thing very simply; now to determine the location of the camera in the scene; that means, nothing, but my E O parameter. So, once I determine the E O parameters I can find out my X 0 Y 0 Z 0 omega phi kappa. So, what does it mean? So, remembered I said that my camera is could be like that could be like that.

So, I am changing the orientation omega phi kappa of my camera while taking the photograph, but at the same time what is the 3 D location of this camera, that is my X 0 Y 0 Z 0. So, these 6 parameters I can determine then I will say that yes we have done the camera calibration. However, I will say that most important is my I O parameters, they are more important to compared to the E O parameters, because once I O parameters are known even I can find out E O parameters using space resection right ok.

So, now, let us look into the camera calibration. So, camera calibration are done by 2 methods; one is method is direct linear transformation or DLT method and another is the most popular method today is Zhang's method right. Let me introduce mister Zhang is a you know chief project scientist I can say chief research scientist in the Microsoft corporation and he has device one method. So, that method is today very very popular and it is very much available on internet fine.

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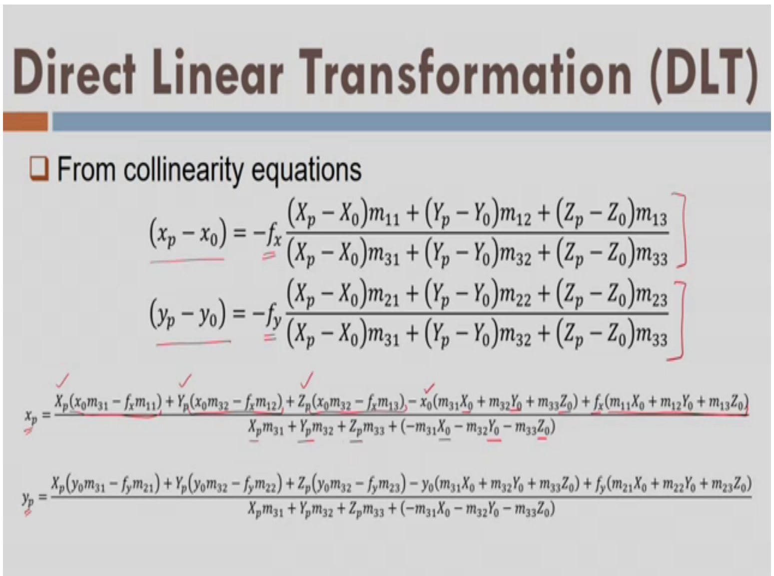

So, let us start with the Direct Linear Transformation or DLT method ok. On the screen I am showing you that 2 equations, which are nothing, but collinearity equation that we have proved it ok. So, I have rewritten these 2 collinearity equations, where you can notice that there is some difference here; f x and f y; that means, I am assuming that the focal length in x direction and focal length in y direction of the camera image are different, but that gives me some advantage; that means, even I am you know I am more precise. I am not assuming the single focal length for the both directions ok.

So, now, let us see that I rearrange my equation like this and like this. So, after this rearrangement I can write this equation and you can just read on the screen and try yourself. So, what is the meaning here try to separate these X p Y p Z p and the coefficients like this try yourself we will find this equations. I could be wrong try that you should find at least you should find correct answers and then these are X 0 and here f x and so well. I can say here X p Y p and Z p and again X 0 Y 0 Z 0. Similarly, X 0 Y 0 Z 0 right ok, I can also in the same where I can write the another equation Y p equal to something ok.

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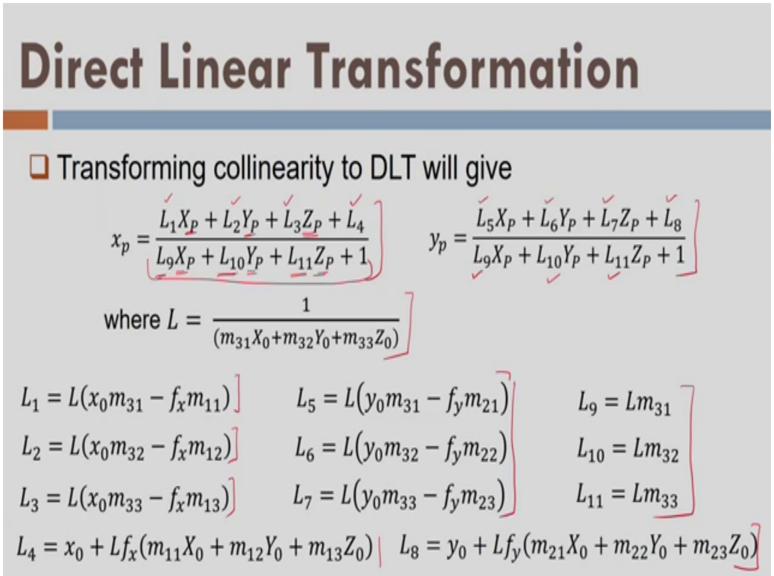

Now, if you look at this equations, I can rearrange those equation again in this form, where whatever the coefficients of Z p Y p and X p are there I am calling them L 1 L 2 and L 3 in the numerator and the remained part I am calling L 4 ok. What about the denominator? I have device this one; that means, I said that there is some X p and there is a multiplicative factor of X p is L 9, similarly there is a Y p. So, I have some multiplicative factor of L 10. And, similarly Z p into L 11, and then whatever is remaining I am saying it is 1; that means, I am dividing that and I am saying that yes I am getting this as my denominator right. Try to write yourself and try to find out what are this L 1 L 2 up to L 11. Similarly, I am writing it for Y p. So, I have L 5 L 6 in up to L 8 in numerator and then in the denominator I have L 9 L 10 L 11 right just note down ok.

Where we define L s like this? Ok. Fine. So, now, we have defined our L 1 as this L 2 as this L 3 as this and so on. All, these are written there well ok. Now, you can understand what does it mean? I have linearize my non-linear collinearity equation, remember there was omega free kappa and all these are contributing to the non-linearity of the collinearity equation.

However, I have linearized it, how do I linearized it? I did I use trailer series no, what did I do I basically club them all the non-linear factors such that they become L 1 L 2 and up to L 11. So, what is advantage? Now, you can recall the similar equation we have solved by the observation equation method. Somewhere in the module 4 and there somehow and advantage you want to derive, because there are 2 ways of solving in problem by a least squares. One is my iterative method and another is non iterative method.

So, in case of iterative method generally I take the non-linear equations I make some kind of estimate of the parameters and I update them. And, I update them till the corrections are 0 of negligible. Now, I need not to do that if my parameters are L 1 to L 11, because I cannot I need not to deal this equation by non-linear way, I can deal it in a very very linear way and that is why it call it a linear transformation ok.

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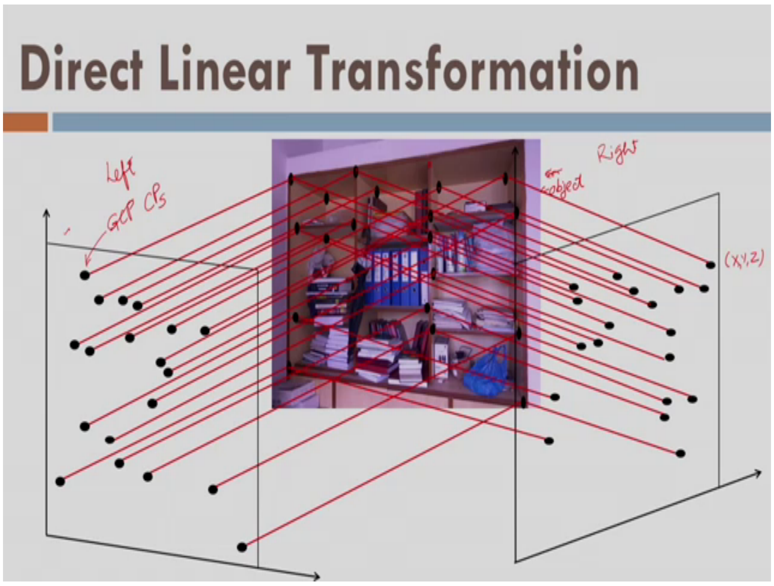

So, let us look into that what is my direct linear transformation and how can I use it? Ok. I want to use it in order to develop 3 D model. So, what I am doing here I am acquiring the 2 images left and right. So, this is my left image here and this is my right image here of the and this is my object here.

So, object is nothing, but an cabinet where some features are there like books files and many many other things, which are you know deliberately put haphazardly; so, that I should be able to develop some kind of 3 D. Now, the idea here is what do you mean by a DLT right? Let us look into that, now what do we deal let us say there is a L point and which has been acquired here and these are the points which are indicated by black dots here and that I want to acquire or other we are taking those points as the my control points of the object. So, let us say like this is my X 1 Y 1 Z 1.

So, it is acquired here in this image as x L 1 in the left image, and x R 1 and y R 1 in the right image right. So, now, you can imagine that other points can be acquired like this also. The moment I acquire 2 images all these points will be acquired rather I can say that 2 images will be acquired like this point. Now, you can just imagine that I have acquired my image and there these points will work as my control point here. Now, I can note down here the X Y and Z; that means, what will I do I will first take my total station or some kind of 3 D measurement unit and I will measure the all 3 D coordinates of these object right.

So, this object this point may be this point this point also possible and so on. Right. In that case what will happen I will observe all these points and I will take these points as my control points in the model? And then I will use the space resection ok. Using this space resection I will find out what are the you know the parameters or the interior orientation and exterior orientation parameter of left image, as well as right image or left camera and right camera since my camera is same. So, I should not say left and right camera ok. So, let us look into that how to determine these parameters?

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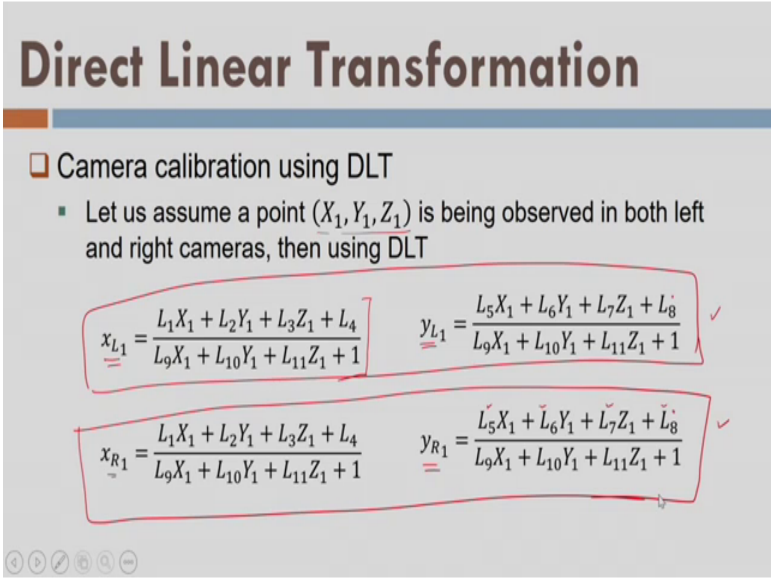

So, let us assume that there is a point X 1 Y 1 Z 1 is observed in both images. So, now, I can write this equation; these 4 equations I can write easily right and I have already modified my equations the collinearity equation in the form of direct linear transformation equations. So, this for left image I have these 2 equation, for right image I have these 2 equations. And, remember these parameters are different from both left and right images.

So, I have completely different business for right and left images. And so, these are not same this and these are not same. Although the camera parameters or the interior orientation parameters of the camera are same remember this thing always. Because, camera is same here and there is no drastic change in the time such that my parameters can or the interior orientation parameter of the camera can change. So, drastically unless I do some kind of you know some kind of mischief with my camera.

So, being a good photographer I have acquired the photograph with minimum time ok. So, now, I want to do the observation equation method in order to solve these 2 equations, this and this both cases are completely different. So, let us look into how to solve this for the left image ok. So, let us write the observation equations for my left image.

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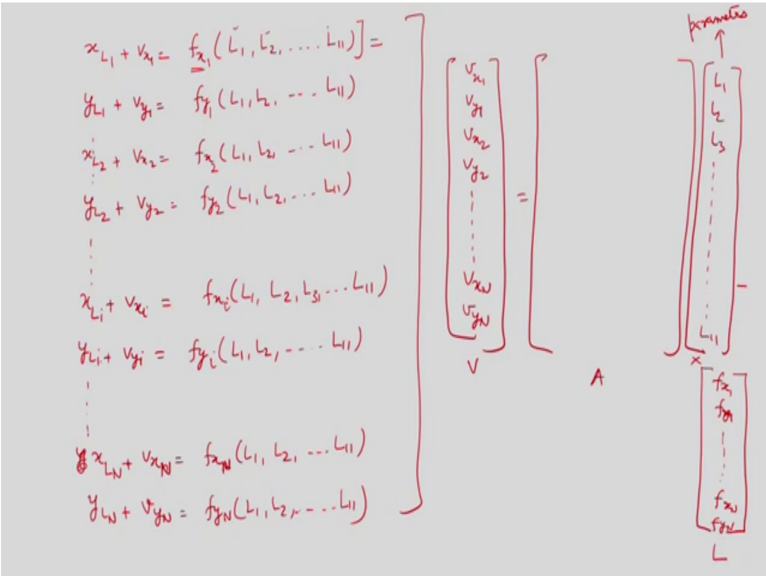

So, what will happen for the first point 1 I can write like this I hope you can agree you agree yourself with this, that L 1 L 2 L 11. Now, I write this equation f y L 1 L 2 L 11 ok. So, let me write for the any point or let me write for the second point. For the third second point in the y direction ok. Let us write for the ith point x L i plus v x i equals to fx L 1 L 2 L 11. Similarly, for the last point I can write here x L N plus v x N equals to fx L 1 L 2 L 11 and y L n plus v y n equals to f y L 1 L 2 L 11 right. Now, I have returned all this observation equations, suppose if I put the values of L 1 L 2 here I will get some values fx for the first point.

So, let me write it fx 1 fy 1 fx 2 fy 2 fx i fy i fx n and fy n right. Now, you can understand these functions are same, but we are writing the values what we are getting from this thing ok. Now, if I write this equations like this I can do all the things, I think I solved a similar example in module 4 and you can do it yourself how to reduce these equations in the form like V x 1 V y 1 V x 2 V y 2 V x N and V y N this my V matrics. And, I will write in the form matrics a and this matrics form L 1 L 2 L 3 L 11, minus some values here that will be my this is my parameters. This is my A matrics, this is my X matrics, this is my V matrics, this is my L matrics, L values will be f x 1 f x 1 y 1 f x N and f y N here.

So, will see that whether plus sign minus sign that is not matter, because answers are going to be same anyhow ok. Now, with this thing if I do this thing here what will happen I will get these equations here.

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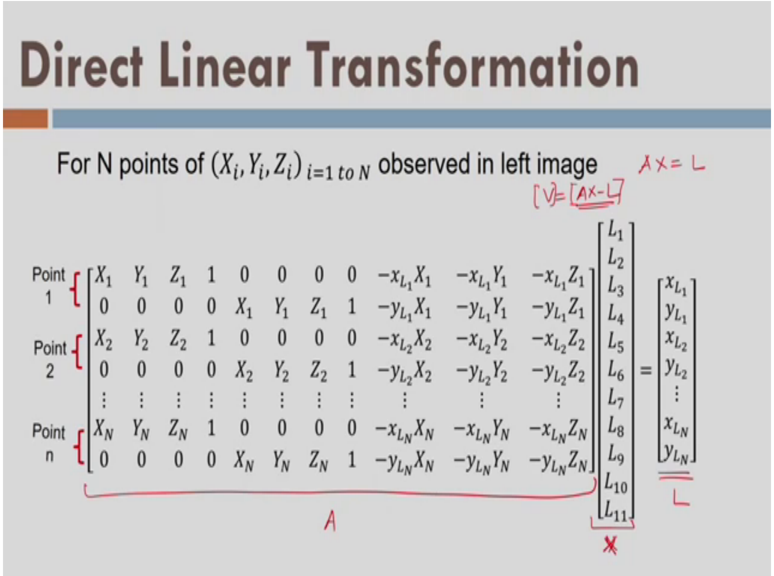

So, this is my L matrics, this is my A matrics, this is my X matrics. So, it is in this form A X equal to L remember I can also write in this form V is equal to A X minus L, where V matrics will be there and here the same matrics will be there right ok. Remember this one L to L 11 are my X matrics fine.

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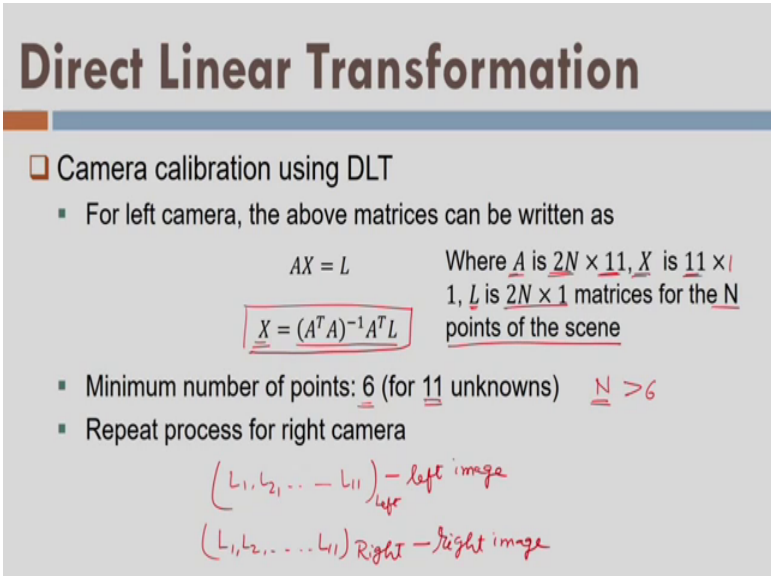

So, once you determine this X values then you can straight away in a single iteration you can determine all 11 parameters ok. So, how many points do I need as a control points, there are 11 unknowns and if I take 1 point it is giving me 2 equations 2 collinearity equation or 2 DLT equations. So, using 2 DLT equations I can find out 2 set of conditions. And, hence for 11 I need minimum 6 points, because the 6 points will give me 12 equations.

And, using 12 equations I can find out 11 unknowns that simple mathematics here is ok. So, the minimum number of points once I take 6 or if I take more than 6 I will go for the least square solution. So, let us say that we have determined the least square solution of X parameter using this equation, where I have some N number of points instead of 6. So, the matrics A is of size 2 N into 11, X is 11 by 1, L is 2 N by 1 for the N points on the scene, remember all N points are my control points right.

So, using the control points I have determined all my L 1 to L 2 for the up to L 11 for left image. Now, I may use the same N number of points to find out L 1 to L 2 L 11 for my right image right. So, let us say I have determined these 2 ok.

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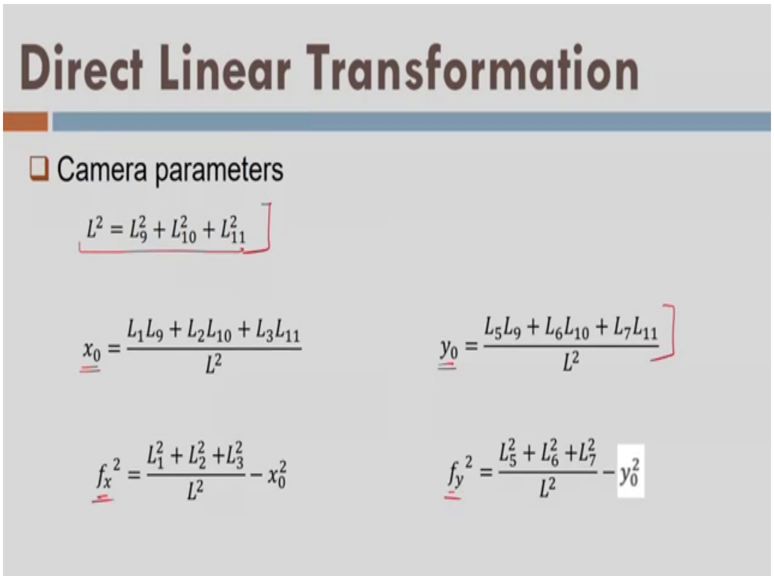

What next? There are few equations that develop of the DLT have presented that let us say that L square is this. Now, if I write L square this is my principal point x 0 and this is my y 0 of principal point.

So, I can using these 2 equations I can find out what is the value of principal point for a particular image it could be left image or right image. So, if I use the parameters L 1 to L 11 I can find out the x 0 y 0 for left image. Similarly, if I use the parameters L 1 to L 11 I can find out the parameters of my right image so; that means, which whichever image parameters I am using I can find out x 0 y 0 and focal length f x and f y for that particular image ok.

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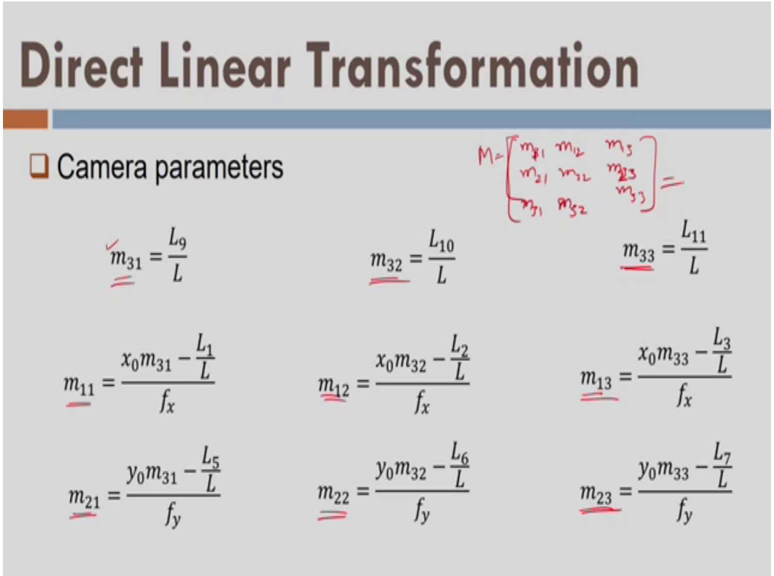

Now, what about the exterior orientation parameter? Remember using exterior orientation parameter, we have created m matrics like m 1 1 m 1 2 m 1 3 and up to m 3 3 here remember m 2 1 m 2 2 m 3 3 m 2 3 I am sorry m 3 1 m 3 2 and so.

So, now, we have this matrics to represent our exterior orientation parameters ok. These parameters are given by these equations and in just one attempt you can find out your all L zeros m everything. And, that is surprising thing about the DLT it is very very elegant method. And so, once you determine these values well by you know again using these 9 elements, you can find out the 3 elements omega 3 kappa.

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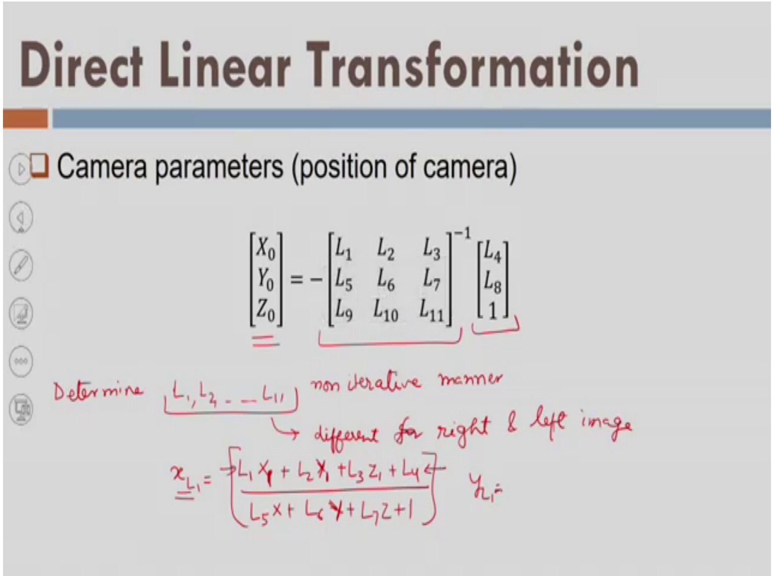

Finally, the 3 D coordinates of the camera position for left image as well as right image. So, now, you use these equations and you can find out X 0 Y 0 Z 0. And, that is the most elegant part of the DLT that first of all you are determined all parameters L 1 L 2 L 11 without iteration or it is by non iterative manner.

So, I have determined and that is why it is called the linear transformation remember in case of linear ways we always find the things very very fast in a 1 iteration. Or without will say without iteration will find out in a 1 attempt. And, that is why it is called DLT. Now, remember here do not do a mistake that these parameters are different for right and left image. So, each left and right image will have different different 11 parameters right do not do the mistake to consider that they are same for 2 images no ok.

Now, let us say you are determined all this thing. So, here we have achieved the camera calibration, but there is a one problem here with the DLT. And, the problem is if you see there were the equation in DLT like this x L 1 we have written, what was the equation, L 1 into x p 1, L 2 into say y 1 let me write X 1 plus L 3 into Z 1 plus L 4 divided by L 5 into X L 6 into Y plus L 7 into Z plus 1, that was the equation right.

Similarly, I can write y L 1 also ok. Now, you can observe that this equation is equation of a plane remember equation of a plane is A X plus B Y plus C Z equal to 1 or some value so, that we can convert it 2 1. So, this is representing a plane equation.

And, you will be surprised to know if I take my coordinates or my control points in 1 plane this is going to be 0. The moment it becomes 0 this becomes 0 or my image coordinate become 0 or this equation of DLT treatment becomes meaningless. And, as a result DLT causes or DLT introduces a limitation in the work. And therefore, for a many many years all the DT DLT was very very popular, we used to develop a kind of 3 D structure in the laboratory in order to do the camera calibration.

And for that purpose only I have shown you 1 cabinet where cabinet has some depth of 1 or 2 feets. So, and I have taken the points at the depth of the cabinet as well as on the front side front panel of the cabinet remember and that was a precisely the reason they have shown you this figure ok. Let me just once again go back perhaps you will be remembering it like this. And, see the points are coming from here you know inside of the cabinet and the front of the cabinet, this is of the front of the cabinet and this point was on the back of the cabinet; that means, all of my control points should not be coplanar. They should be in different different planes and then we can use the code DLT and yes that introduces a big problem and that is why finally, Professor Zhang or Dr. Zhang has introduce a new method and that was much elegant than DLT. Yeah.

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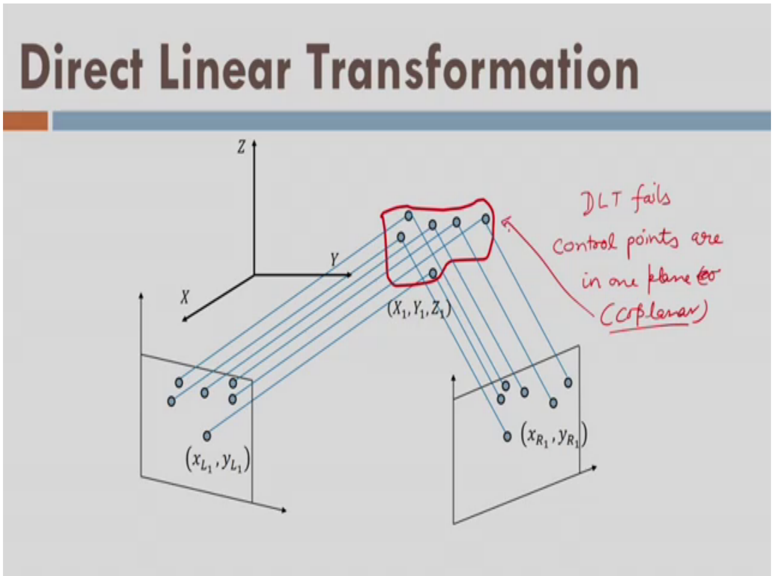

If, you say that let us say this is the plane and where all the points are in the plane. So, in that case the DLT will definitely fails, because control points are in 1 plane or they are basically I call it coplanar like this fine. So, now, what happens here is we should learn the now Zhang's method with says that my control point should be coplanar. And, this is the way much more elegant method becomes the Zhang's method.

Zhang's method says that my all the points should be coplanar or all my control points should be coplanar. And, that is the reason Zhang's method becomes much more elegant and much more popular now. So, let us look into the Zhang's method.

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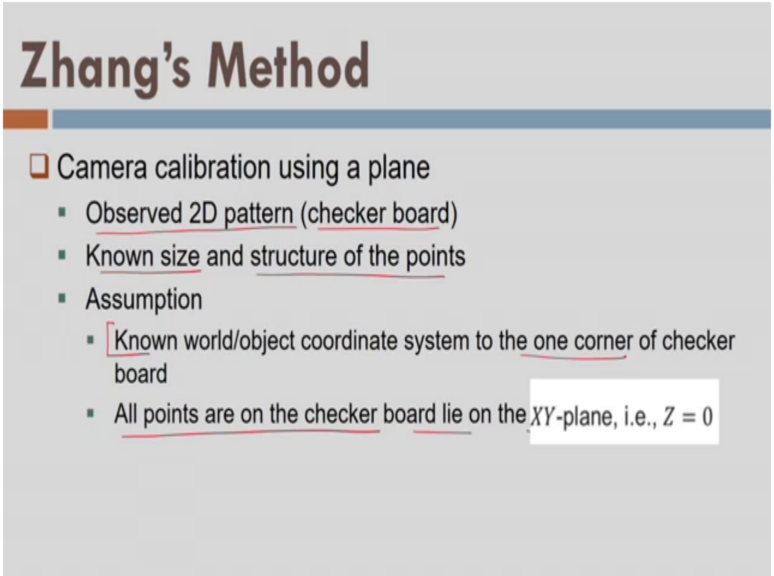

So, let us start with the Zhang's method. And, the Zhang's method says that you want to do the camera calibration using a plane and the coplanar coordinates only. The control points should be in 1 plane coplanar ok. So, let us observed the 2 D pattern or the checker board right, where I have known sizes of the object and structure of the points well and assumption here is that the known world or object coordinate system the origin is the at one corner I will explain what is that. So, all points are in the checker board or the object is in the one plane; that means, there in the XY-plane and so, my Z is 0. What does it mean?

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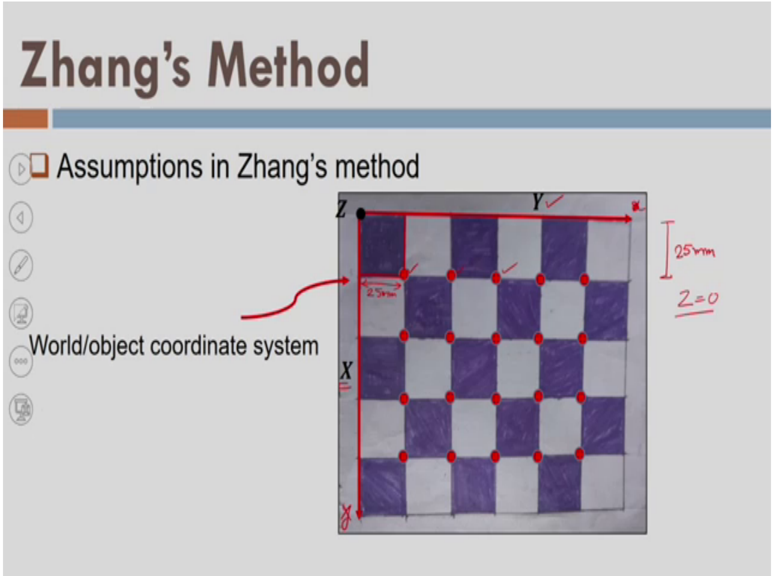

So, let us see this is my checker board, that we have designed and we have used it also in the last lecture for forstner operator. Now, let us see that we place our X and Y coordinate like this let us say this is Y coordinate and this is my X coordinate. And so, my Z coordinate which is perpendicular to this checker board will automatically be 0, because all these objects points.

For example, this point this point this point this point and any point in this plane the line single plane X Y and as a result my Z equal to 0. Remember in case of DLT we say that my control points should not be in the plane they should be in different place. So, that you will have realty will not fail rather Zhang's method says they should be in the plane surprising ok. So, now this is my XY and Z where Z is 0 these are my control points now they becomes control points. So, idea here is fine this side I know this side I know.

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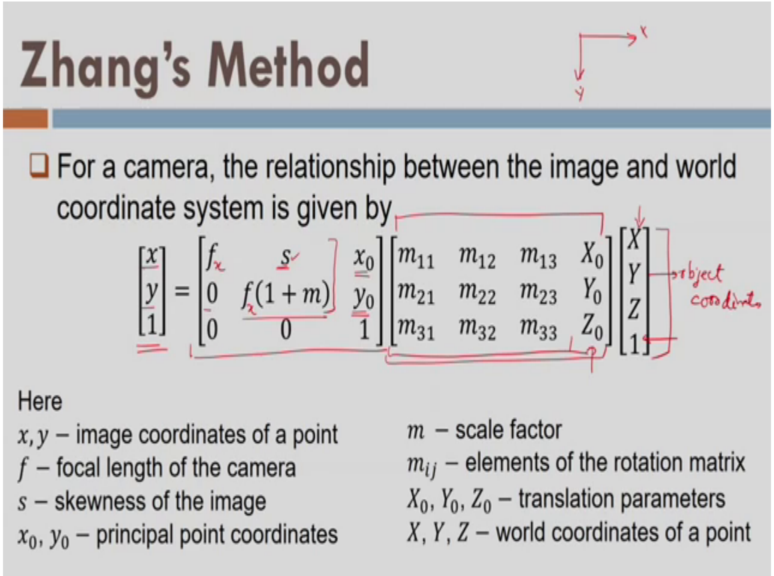

So, as a result I know the dimensions of my checker board and I know what are the control points right. With the help of some image mating technique and with the help of let us say some algorithms like shift that is scale invariant feature transform. These points which are called control point in the object can be identified automatically. And, as a result now the camera calibration process becomes completely automatic, because of the image identification or the feature identification number 1.

And, second the Zhang's method which says there is no problem, even if they control points are in the 1 plane. So, let us look into the fundamental idea of the Zhang's method ok. I am representing my collinearity equation by this equation I will tell you this is my exterior orientation parameters here this you do not have a doubt. These are my translation and I am writing them in a way that I can integrate all this parameters in 1 matrics using homogenize coordinates.

So, these are my object coordinates and I am using 1 here there one. So, that I can integrate all the exterior orientation parameter in 1 matrics; that means, all 6 parameters are there in 1 matrics well. Now, this matrics if I just look at if you remember this is nothing, but any scale matrics here. So, I say that remember it was f x and it is nothing, but f x time 1 plus m. So, I am saying that instead of writing f y I am writing f y like this.

This is my skewness that means remember if there are 2 parallel lines and if I distort them like this right. So, this edge or this edge will be little distorted compare to these edges. So, this kind of distortion when happens in a plane we call it skew. And, there is a this factor we are also involving and these are my principal points. So, again I am writing my interior orientation parameters f x 0 and y 0 in again in a 1 matrix. And, now we can write it very easily that is possible mathematically.

And, then we say that this is my image coordinate X and this my image coordinate Y that I am going to observe corresponding to these XYZ in the object coordinate system ok. Again, my object coordinate is my checker board that I already know and remember if I fix the object coordinates like this capital X and capital Y the way I have shown you in the last slide here. So, this is my capital X. Remember this is capital X not the small X similarly this is my capital Y ok.

So, in that 2 dimension so, does not matter even if you switch so, X and Y does not matter. So, I can measure all these coordinates and again by automatic processes it is possible to measure, why because I know, what is the size? This size for example, we kept around 25 mm.

So, I know that this is also 25 mm. So, if I find this point here and I know already vary the origin is I can find out what is the coordinate of this point this point this point and so on. So, let us understand the beauty of the Zhang's method fine. Now, let us rewrite this equation Zhang's method equation and some fashion ok.

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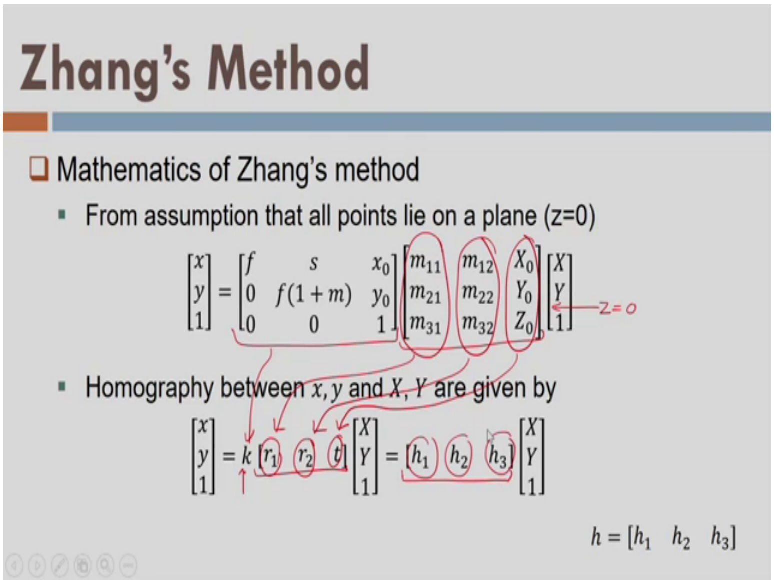

So, I am writing it like this that write this matrix. So, this is my r 1 this is my r 2 and this is my translation te ok. So, what about my Z? I think something is missing here remember Z is 0 here it is missing here right do you no need to write it. Similarly, now this is my k which is equal to this complete matrix k ok. If, I multiply k and r I will get 3 columns h 1 h 2 and h 3 and that is what we call the homography between the x y and capital X Y.

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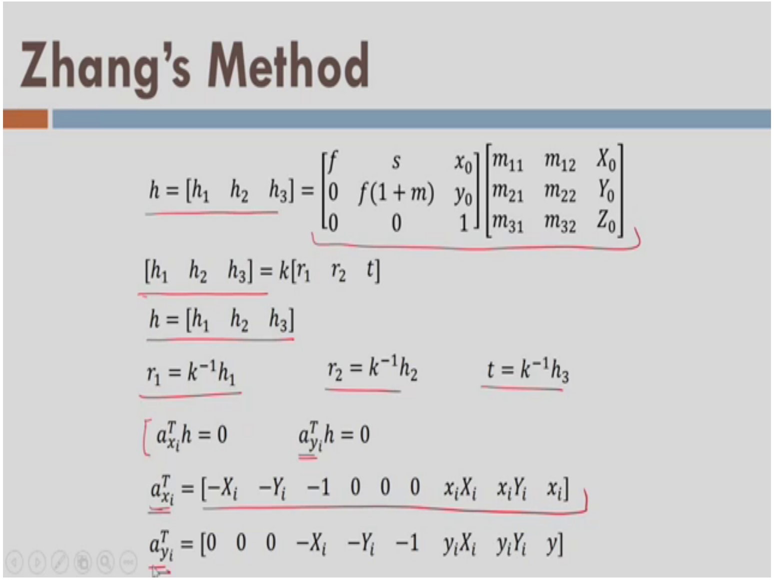

Now I can write my h like this where this is this. So, I can write h 1 h is this r 1 is this r 2 is this t is this. And so, I can write here a 1 xi dot h equal to 0, where this is also true what is my a x i a X i is this one, this matrix here. We can try it yourself by just opening these matrices and try to write all this thing fine ok.

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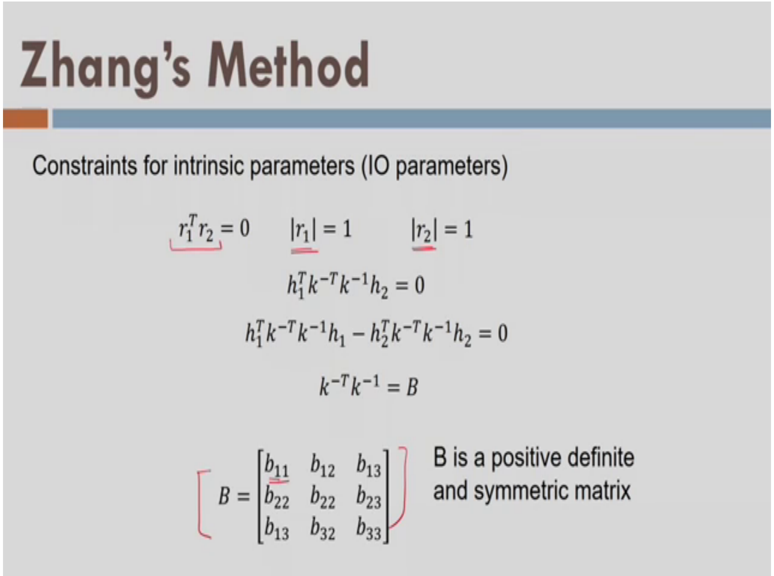

Moreover ultimately, we also know that r 1 and r 2 is equal to 0 because they are orthogonal to each other; that means, inverse of r 1 is equal to r t and if I multiply r 1 r 2 t they will become 0 right. Secondly, this is also true this is also true ok. Using these finally, we write some kind of b matrix here like this. And, well that is the idea here now we solve for the b matrix or the element of b matrix. And finally, we find out the interior orientation parameter of the camera, that is side and the Zhang's method well.

Going further into Zhang's method one can refer the famous paper and Zhang's method and that paper we have shown in the last light on the screen on this presentation. So, wait for a couple of slides. However, I would like to emphasize what is the practical significance of the Zhang's method, that is much more easy to understand right.

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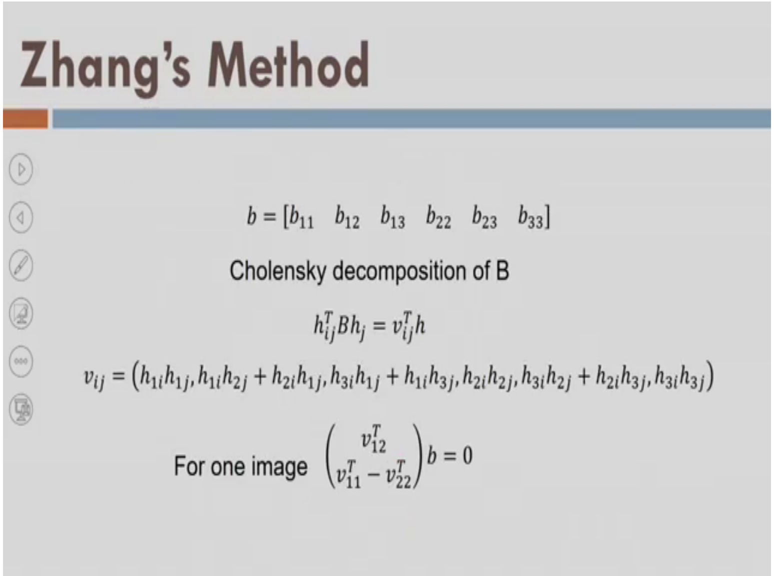

And, so how to implement Zhang's method it is more important now, what is required?

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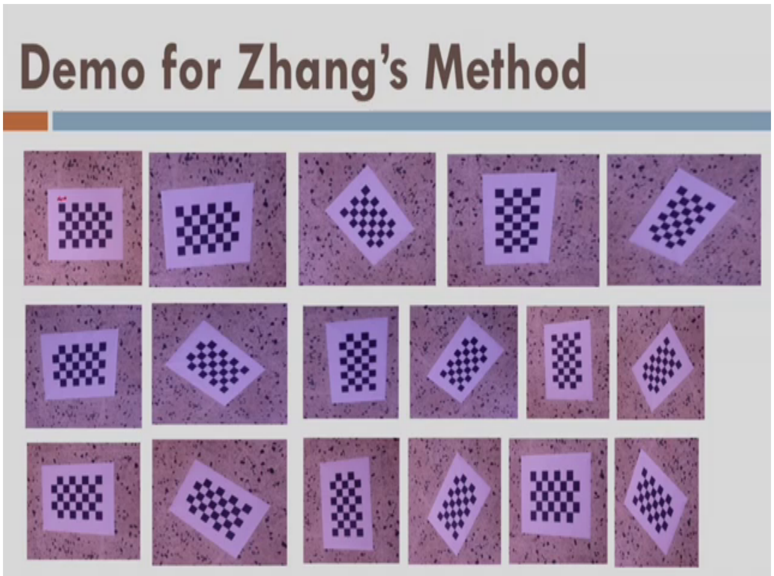

Yes, the first thing has how to acquire the data for the Zhang's method remember, we have said that we need a checker board. So, there are some standard checker boards are available on net or even you can print it yourself, to print them where this dimensions are well known. And, you need not to write do anything the especial tools we read for you what is dimension of this and you have to give on the dimension of the you know whatever let us a 37 mm 35 mm whatever.

So, the movement you acquired the photograph of this checker board from all the sites. So, you need minimum 3 photographs for this method, but if you take more photographs you will get (Refer Time: 41:40) and measurement or more accurate result on your calibration parameters fine. So, let us say we have acquired this way. So, we have all roam around using our camera around that and we have acquired the photographs like this.

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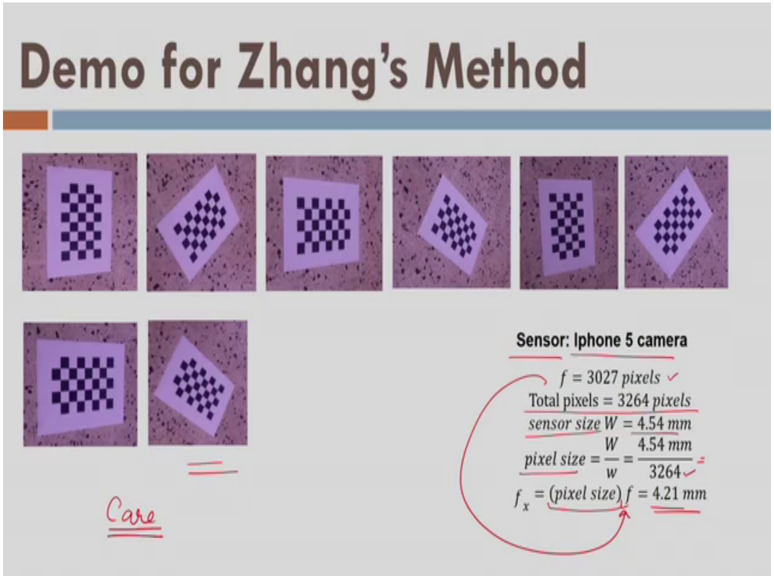

And this is. So, total some number of photographs we have acquired ok. And, we have done this job using our sensor call iPhone 5 camera which is an consumer great camera and then we have find this results f equal to. So, pixels so, total pixels in the that sensor of iPhone was so, much and the sensor size was so, much. And, as a result the pixel size; that means, the size of the pixel on the sensor is so, many mm divide by so, many pixels right.

And, now I will use this pixel size to multiply with this f value. And, I got this my answer well I try to find out whether this answer is correct or not and I found it is very much correct and that is a beauty of Zhang's method you might have realize now, that how to use the Zhang's method ok. There should be some care. Remember 1 should be very very careful in order when they used a Zhang's method or when they use the camera calibration for close range photogrammetry.

And, the idea here is whatever distance you expect at the sight between the camera and the sensor you should use the same distance for the camera calibration. So, that is a again 1 more advantage to the Zhang's method; that means, you instead of putting this checker board on some surface and doing some kind of camera calibration in lap, you just go in the field and put this checker board on the surface of object. Take a photograph wherever you can take and you know that now the distance between camera and the object is equal to the distance between the checker board and the camera.

So, now you are doing your camera calibration very very appropriately right. And, that side we should follow. So, what will do you will do the camera calibration first from the site and then you will use those camera calibration parameters. In order to determine the 3 D coordinates of the object right. And, generally what we do now, we are calibrated on camera either by DLT or Zhang's method I want to generate my 3 D. So, let us look into that how to do that?

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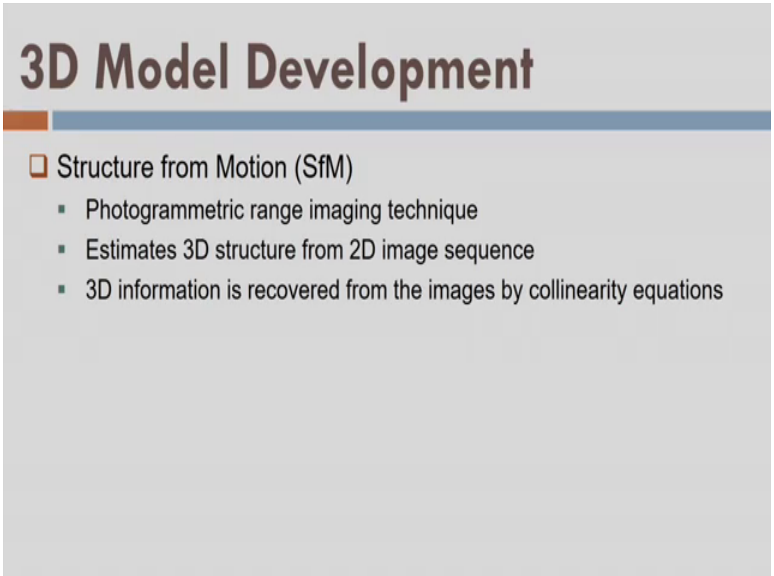

For that purpose we use structure from motion algorithm. What is structure from motion yes the SfM algorithm says, let us say there is an object like this. And, it is moving like this ok. So, I want to capture this movement, what can I do I will put an camera like this my hand. Now, let us let the object to move like this or like this whatever and now I will keep on acquiring the multiple photos, what will happen this movement will be captured in multiple photos. And, I can find out what is the rotation speed something like that ok.

Again people have derived some other method being a human they are very very intelligent. In case of esthetic object let us say object is static like that, what do you say object is not moving rather we will move our camera. And so, again we are doing the same thing and that is why this algorithm is called structure from motion; that means, I am deriving a 3 D structure by moving my camera or maybe the object is moving, but my camera is static or other way around there is object is static my camera is moving around the object. And, I am acquiring the stereoscopic photographs or the overlapping photographs and I am using conversion photogrammetry not the stereoscopic.

Please remember the stereoscopic coverage means the way I am using it for the purpose of overlap. So, I am acquired in the overlapping photograph, but using convergent photography; that means, all my photographs are converging or acquiring the information, that information is converging at 1 place that is my object will see in the next slide what does it mean. So, it is and photogrammetric range imaging technique where I acquire the 3 D structure from 2 D image sequence; sequence means an acquiring overlapping photographs ok. And, then we recover the 3 D information from the all sequence of photographs ok. Let us look into the what is this mean?

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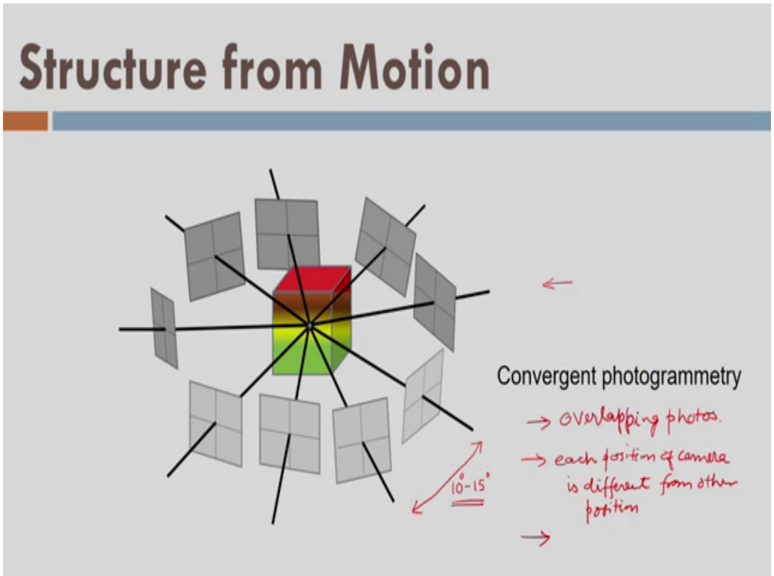

Let us say there is a camera here and there is a object here ok. I will acquire my photograph like this, then I will move my camera like this acquire next photograph. One more photograph I have changing my orientation of camera and acquiring the photographs like this. As shown in the screen the animation is very very beautiful to explain the process ok, I hope you are understanding what does it mean. So, I have changing my orientation of camera and I have acquired so, many photographs and all these photographs are overlapping photographs and number 1 thing ok. Each position of camera is different from other right, any other thing that you want to observe we can write your own notes.

So, that is a problem here and that is the magic of the SfM moreover I would like to say here in general as per the guidelines available this should be around 10 to 15 degree difference here. So, I have shown you around 1 2 3 4 5 6 7 8 photographs, you can acquire depending on the size of the object and depending on the available space we can acquire many many photographs. And, there once you acquire the photographs; you use some standard procedures like space intersection space resection and so on.

In order to first calibrate your camera and find out the 3 D coordinates of your object, and that you can do it very easily right. And, we have done it and we have realize it yes it is quite possible to use SfM in order to generate 3 D views, in the close range photogrammetry and it is completely automatic now. So, now I am showing you the bicycle project, what we have done here at IIT Guwahati, we have taken one bicycle and we have generated these 3 models like this.

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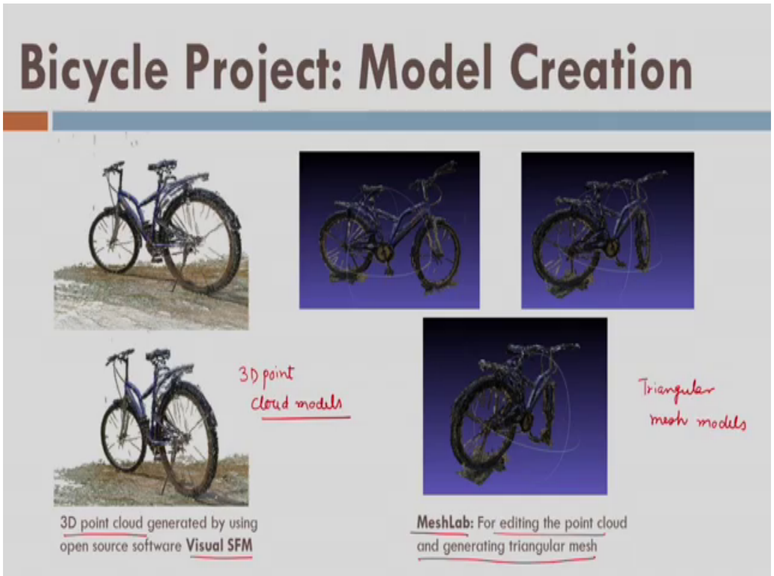

So, 3 D point cloud generated by software called Visual SFM which is free. And, these 3 more models that we have further we use the 3 D point cloud generated by the SFM visual SFM software and then we have done some kind of processing over there using MeshLab software and that is also free. So, then we have done the editing and generated the triangular mesh. So, these models are triangular mesh models and these are the point cloud 3 D point cloud models.

So, you can also do that SFM and you can also use be complete close range photogrammetry to develop maps as well as 3 D models. Now, tried yourself for your at least your home or at least your university building or at least the administrative building or the most beautiful building in your campus try to do that. Remember that building is there and you can move it around you can acquire the photograph and now you can do the magic there ok. Try to do at least for one building or you can do one more thing very interesting thing you are 2 friends.

So, one friend should become like a statue just stand on one position another friend will acquire the photographs and try to recover the 3 D structure of your friend most interesting exercise. And try to see, whether you can get all the curves on your faces moustache, hairs, texture of hair ok.

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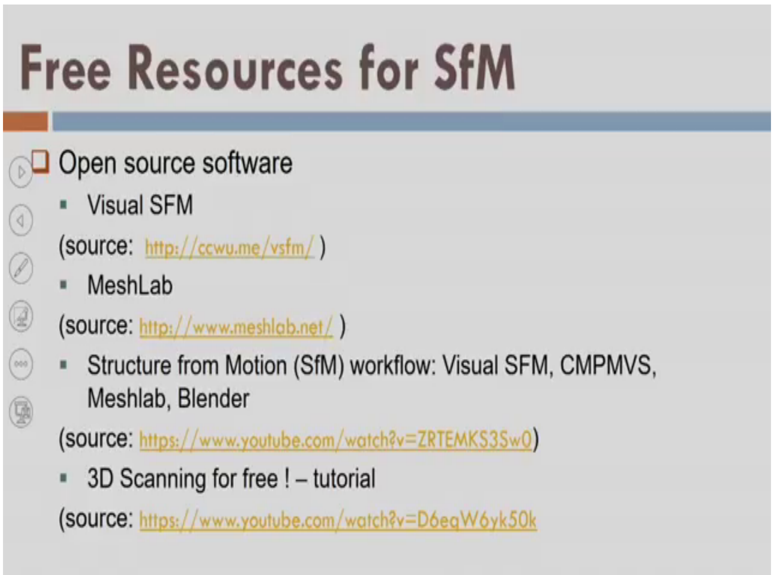

And, then we suggest you to use all the softwares which is first is Visual SFM is available on this link, then MeshLab is available on this link ok. What about this SfM workflow? Complete workflow about using SfM CMPMVS Meshlab and Blender software is available on this source of YouTube; we have used it personally and we found it very useful. Again, this is a tutorial about the how to use the photography or how to acquire the photographs using SfM or for the SfM it is available on the source of YouTube. So, there are many many exhalent guidelines are available today to use SfM. Now, you can develop your own 3 D models; is it not very beautiful ok.

So, somehow I believe that the photogrammetry has stress this a lot, but yes it has given you complete sense of how to collect the complete 3 D information from all possible ways. It could be aerial photograph, it could be satellite photograph, it could be terrestrial photograph, it could be a drone photograph, it could be a close range photogrammetry or it could be far range photogrammetry, it could be anything you can do it now. And, I have full belief that you have enjoyed this module and here we finished this module today. And, next module is my related to the LiDAR, that is Light Detecting and Ranging. So, we will meet in the next module.

Thank you very much.