Higher Surveying
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Module – 6
Lecture – 20
Photogrammetry

Hello, everyone. Welcome, back on the course of Higher Surveying and we are in module – 6, Photogrammetry. We have already completed 5 lectures in this module. In the last lecture, we have discussed about a space resection, a space intersection, the combination of two is called aerial triangulation, further we talked about bundle judgement and self calibrating bundle adjustment. Apart from this we also learnt what is absolute orientation and what is relative orientation of this stereo models or maybe the stereo images, ok.

We have learned many many things they are computationally, that means, computational photogrammetry. How computer works for you if you are using photogrammetry for a stereo images. Well, now let us assume that we have done our computational work completely and we have created 3D coordinates of the some of the points. So, let us understand that we have done some measurement on our stereo periods that is x 1 y 1 and x 2 y 2 to image coordinates or maybe more image coordinates, if there are more number of stereo images are there for one point and then using all those points we have find out what is the 3D coordinates of the terrain point, that we have done in the space intersection process, ok.

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So, let us today start with the whatever we can do with this available 3D points that calculated as a part of the space intersection process, right and today we are going to discuss about the photogrammetric products. And, there are two products which are very very popular and one is the digital elevation model and the other as orthomap, orthoimage or orthophoto.

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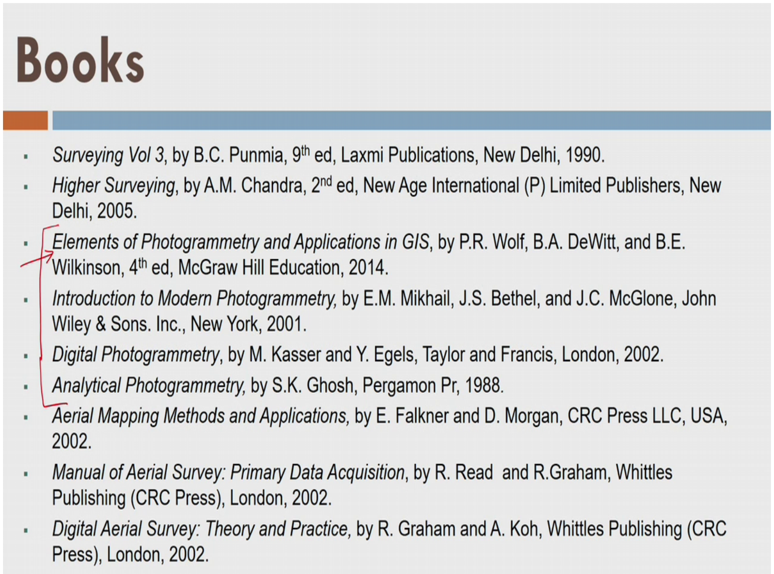

So, let us start here. Here again there are fundamentally these 4 books where this book is again available in India, ok.

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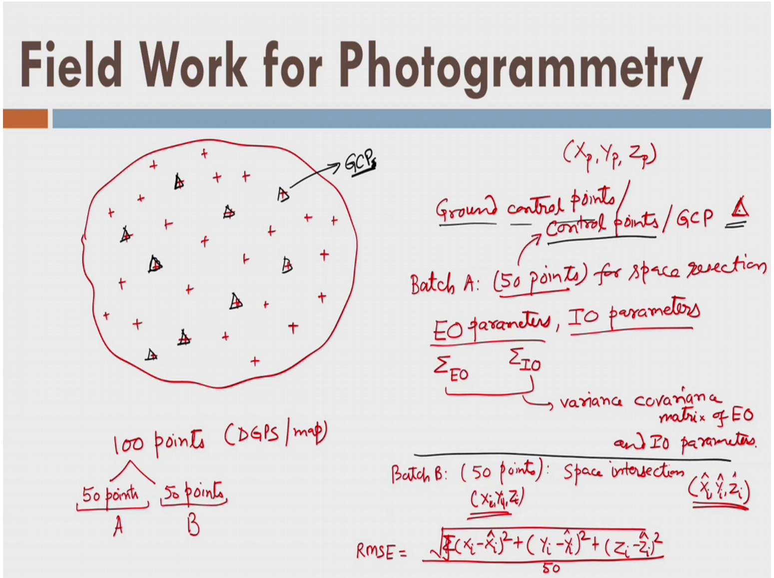

Now, first of all in the last lecture with talked a lot of things about when to use what? That means, when to use control point when to use when to calculate our terrain point and so, there was some kind of you know we have used a terminology every time for a ground point called X p, Y p and Z p. Now, I would like to clear you few of the things, right. Let us say there is a terrain given like this and in this terrain there are points like this which are uniformly distributed and for this terrain you want to create 3D coordinate for some points.

So, let us say that you have collected using DGPS or maybe map these points with very high accuracy, all they are uniformly distributed right and let us say they are 100 points you have collected in the field; let us say by DGPS or by map, whatever and you know the accuracy of those point, ok. Out of those 100 points what will I do now, I will divide this points into 50 percent two slots and remember this 50 points are also uniformly distributed on the terrain. That means, let us say I am collecting these points ok, let me call it like this these points which are uniformly distributed, right.

So, you can now see that remaining points which are plus mark without triangle they are also equally and they are uniformly distributed over the terrain. So, let us say this is batch A and this is batch B. So, I used batch a 50 points for space resection, remember this 50 points are more than our minimum number of points which are require for this space resection.

Now, as a result since the number of points are more than the minimum one I will go for the least square solution and I will find out exterior orientation parameters and if I am using self calibrating bundle adjustment, then I will determined IO parameters also, right. Not only that using error propagation I will find out what is the stigma EO and I will also determine what is sigma IO. So, that is nothing, but the confidence or I can say here variance covariance matrix of EO and IO parameters, right.

Now, here you can understand that this is sigma values are going to give me the quality of the parameters, ok. So far we have done thing, no problem. Now, what will I do in general these points are called control points or ground control points or I can say here ground control points or control points or they are written as GCPs. Now, very popular name GCP: Ground Control Point. Well, this ground control points are used for the calculation of parameters EO and IO parameters or rather developing a mathematical model for our image, for our image and object relationship or the image and object transformation, fine. So, we done that thing.

Now, this points are generally indicated by triangle or there is a dot inside triangle, both conventions are there you can use anything point. So, that is why made here black triangles around those plus points. So, it is like that. So, they are all control points now. So, I can see here let us see they are my GCPs ok, GCP (Refer Time: 07:05) ground control point. So, collectively they are called ground control points the GCPs. Well, where this term use call control points is used? Well, photogrammetry is being used by many many people now, mechanical engineers, medical science people. So, what they do they do not collect the point on the surface of terrain rather the collect the point on the surface of a body or surface of a machine. So, that is why they use the term control point.

However, in photogrammetry for terrain mapping means always use the term ground control point and GCP, well. Well, now you understand what is the GCP and how to indicate it on the map or on the maybe any paper, fine. Now, this some more term now this there and terminology is what about batch B? They are remaining 50 points, fine. What will I do? I will now do the space intersection for those 50 points, right, ok. I already know the X, Y, Z from the DGPs survey or the map. Also, I am determining this let us say X hat, Y hat and Z hat call it i i i for i point. So, it is call it i i and i, right.

Now, I can find out the accuracy on these points because I have from the field and I am calculating using space intersection, in the space intersection I have used this EO and IO parameters well. So, now, let us see how to calculate the accuracy and accuracy will 3D accuracy I am telling you, X i minus i hat square Y i minus Y i hat square plus Z i minus Z i hat square and under root is there then summation sine and then let say if you are doing for 50 points so, divide by 50 and let us say this is my RMSE, right, 3D error.

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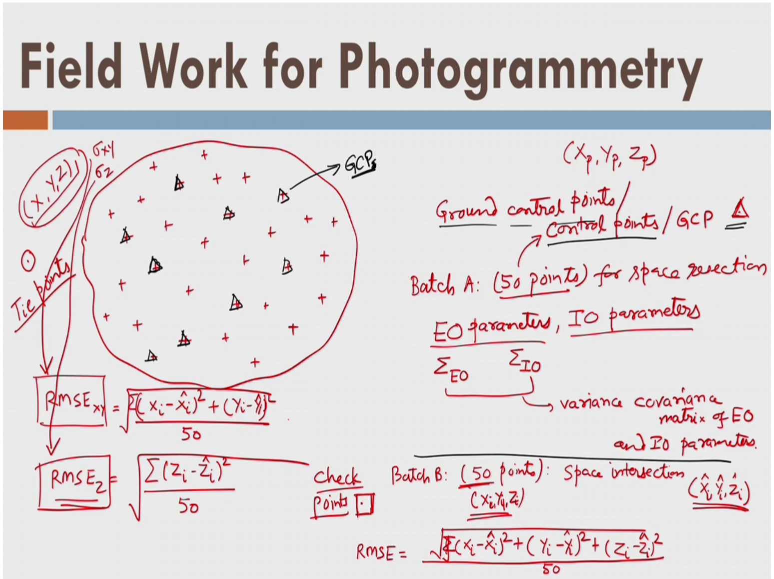

Similarly, I can also find out RMSE for XY like X i minus X i hat square Y i minus Y i hat divided by 50 and RMSE Z Z i minus Z summation that. Z i minus Z i hat square summation over 50 points and divided by 50. So, that is my RMSE Z and now, that is the quality of my work here or the quality of my prediction. And, these 50 points which are called used for the space intersection I called and checkpoints because I have used them for the accuracy analysis or the accuracy evaluation, right.

So, once I evaluate the accuracy over this 50 points then now I can confidently say see 50 is not a limit, but for my confidence according to given terrain I am saying this thing. So, even sometimes you need 500 point also. So, do not stick to the point 50 here, right. So, these points are called checkpoints and they are indicated by square like this. So, now I know: what is the accuracy of my prediction, fine. I will get some RMSE Z here that is my vertical accuracy of the prediction or I also know: what is my planning material accuracy.

Now, if I use n number of other point which are not this 100 points, right, where I predict the Z value X value and Y value; that means, I am taking image coordinates and then using stereo concept or the photogrammetric concept I am predicting their coordinates let us say X, Y and Z. But, I can know confidently say based on this performance of the checkpoints that each of this point are calculated with sigma X Y accuracy sigma Z accuracy, where sigma Z my this one and sigma Z is my this one RMSE Z. So, that is the idea here.

Now, such a point where calculate like this points I call them tie point and they are indicated by circle or maybe circle red dot. So, their third point of type of points called tie points and photogrammetry. So, now we have three type of bifurcation of the points ground control points which are use for the for the space resection. Now, we have checkpoints where we evaluate the accuracy of a space intersection and then we have tie points where we generate the 3D coordinates. And finally, let us say we have n number of tie points it could be 1000, it could be 500, it could be whatever a perfect terrain as per the resolution or as per your DEM and, but they are coming from some accuracy called sigma Z and sigma XY where sigma XY is my RMSC XY and sigma Z is my RMSE Z evaluated over the checkpoints. So, this concept should be very very clear to you, ok.

So, let us see we have done this thing we have generated our tie points, we have generated the 3D coordinates of our tie points. Now, with these 3D points of tie points I can generate something called digital elevation model and that is my first product of the photogrammetry

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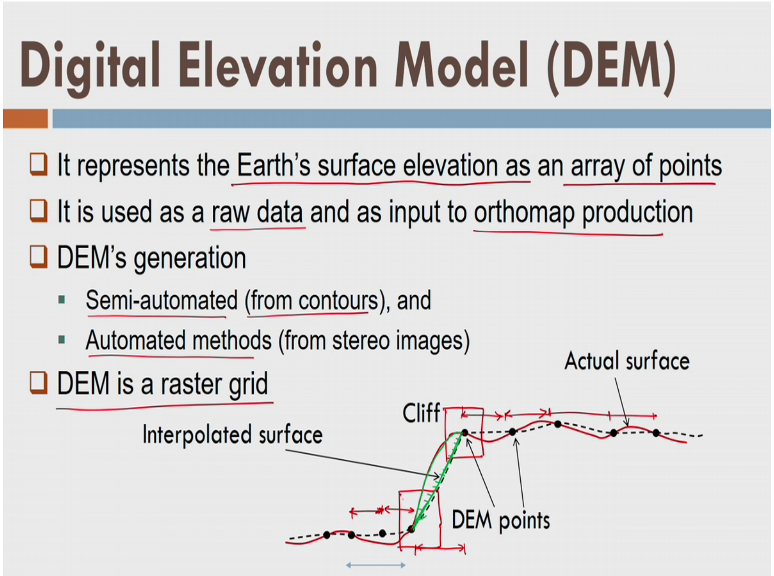

And, this digital elevation model its representation of the earth's surface elevation as an array of points which means, since now we can imagine that for each and every point on the image I am not going to develop this tie points. However, I will take majority as per my convenience later on what will I do I will arrange them and I try to make square grids right such that I can interpolate this one. So, what is the meaning here? Ok, before that we go into that let us understand the two processes; one is automated process that we have learnt in photogrammetry and this another process called semi automated process.

And, this semi automated process when we generate digital elevation model from contours and this is categorically and clearly explained in the basic surveying course you can review there the module on levelling and contouring, it is well explained there. Now, we use this DEM as a raw data for the orthophoto generation or orthomap generation or orthoimage generation, right and DEM is basically raster grid what is that let us look into that. And, again you can review the basic concepts of the surveying in the basic course called surveying, again revisit the module levelling and contouring, ok.

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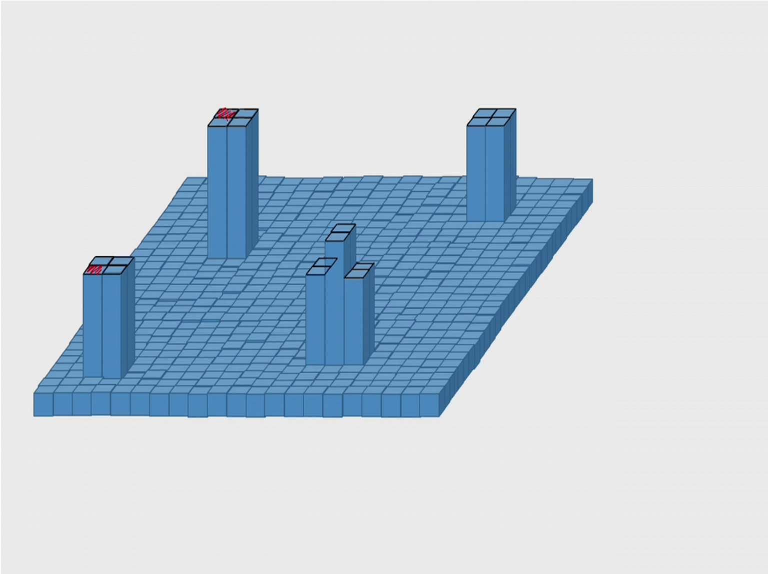

One more thing I would like to say here that let us see these are the predictions, we will come back here, ok. So, let us say we have calculated our 3D coordinates and after that we have created this kind of grids by interpolation because at each and every point of the image I have not calculated the tie points or the 3D coordinates of tie points, but I want a complete this kind of grid for the whole terrain. So, what will I do using those points which for which I have calculated my 3D coordinates I will do the interpolation and the interpolation successfully creates this kind of grid. And, this grid kind of system where each value on the X i pixel is indicating with the height it is called DEM digital elevation model, right.

Here, I can say that this pixel is indicating the height of this building, similarly this pixel is indicating the height of this building and all 4 pixels are indicating height of this building. So, we can see that, ok. Now, if I go back for the purpose of interpolation I would like to mention here is. So, these are the points I obtained from the DEM like this. So, this is my kind of spacing of the DEM like this yes this not uniform which is not true then we will have uniform spacing in case of DEM. So, let us assume that these points are generated by DEM at uniform spacing; that means, my pixel size of the DEM is fixed, ok.

Now, you can see here this is my actual terrain which is shown by red colour or the red line ok, the DEM points are these black dots or black circles. As a result what happens if you see that this is the pixel of my DEM and here this is the pixel of my DEM here. Let us assume that they are uniformly distributed. Now, this is the point here, this is the point here from here to here this is the real terrain which I am following ok. However, I have to interpolate it like this is my interpolated length and assuming straight line between the two, not the curved line, but my real terrain is the curve. So, DEM is according to it is resolution and accuracy. It is a closed to the true representation of the terrain not the best presentation.

But, still it is very close to the true and that is why we need to have some kind of accuracy measure also for the DEM. That means, what is accuracy of the my DEM? What is the Z accuracy? What is planimetric accuracy and according decide the cell size or the resolution of DEM, right. You should understand this aspects very nicely very clearly why because let us say that you have generated some 3D points of tie points using space intersection process. And now, you want to generate a DEM as a product to give it to your client or to give it to your research community or use it for a research project then what should be the size of the grid size or the cell size or the resolution of your DEM you should keep ultimately, right. That decides your later work or the application of the DEM. And, for that purpose you should understand one very simple thing that what is the accuracy of a 3D coordinates that is given by the space intersection.

So, once you know that you can decide what is my planimetric cell size and what is my vertical resolution or the vertical accuracy of my DEM. So, let us go into the DEM now, ok. So, I have already explained you this part, fine.

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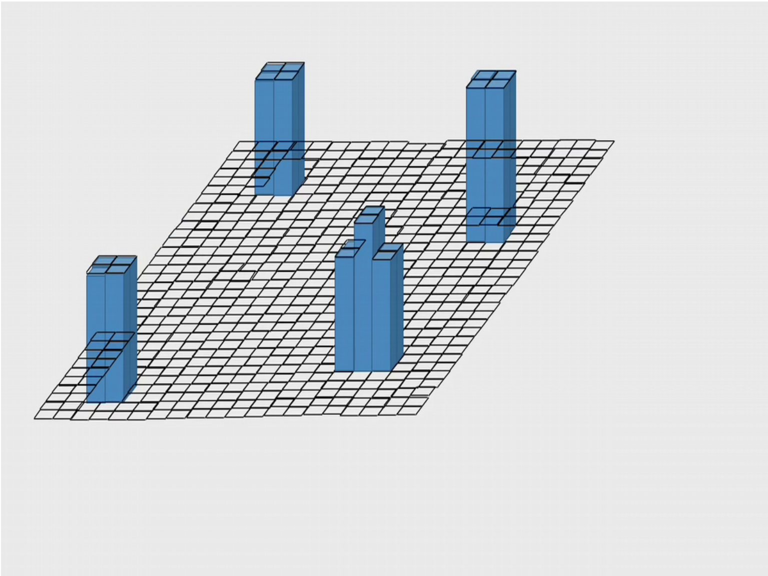

So, let us see these are the grids we have generated and now, if I remove these buildings.

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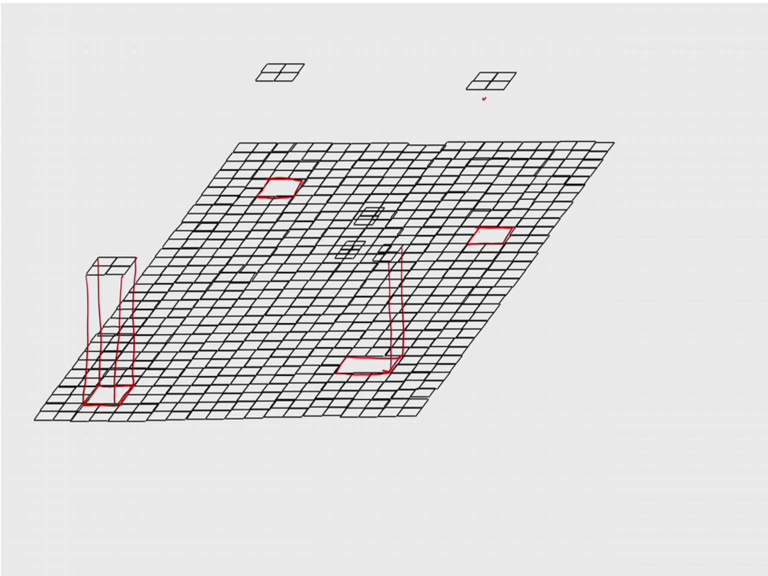

So, my this is my DEM. So, each and every grid is telling you some height information as well as X Y information where it is situated. So, the planimetric location XY and the Z information and remember it is not a pseudo three survey. It is a complete survey in the sense it is a true 3D survey because this the photogrammetric process if space intersection has generated 3D points in one attempt not in the different different style.

And, if I use the DGPS this heights are indicating ellipsoidal height, but if I use the orthometric height in my GCPs, then these heights are indicating the orthometric height of the building I hope you should be very very clear on that part. Now, you can see this is a footprint of the building here, right. Similarly I have another building here and this is the footprint here, same way we have some footprints here and for this building we have footprint here, and for this building where we have three towers we have footprint here.

Now, what about this line? Yes, DEM assumes that they are vertically connected, they are linearly connected although we know that building, but however, in case of real terrain this curves are not very straight, not guaranteed to be straight most of the time there very very curvilinear. And, so, we should be very very careful if you do the terrain survey or by photogrammetry in the field or in the forest or in the somewhere natural ground or in the urban area, ok.

So, according to the situation or according to terrain we should understand these aspects. Photogrammetry does not understand this thing. We have to understand and we have to interpret it physically. So, this is again the vertical here and we are happy here because we know that for a building this should be vertical walls, right. So, we should interpolate it like that only similarly I can draw for other buildings.

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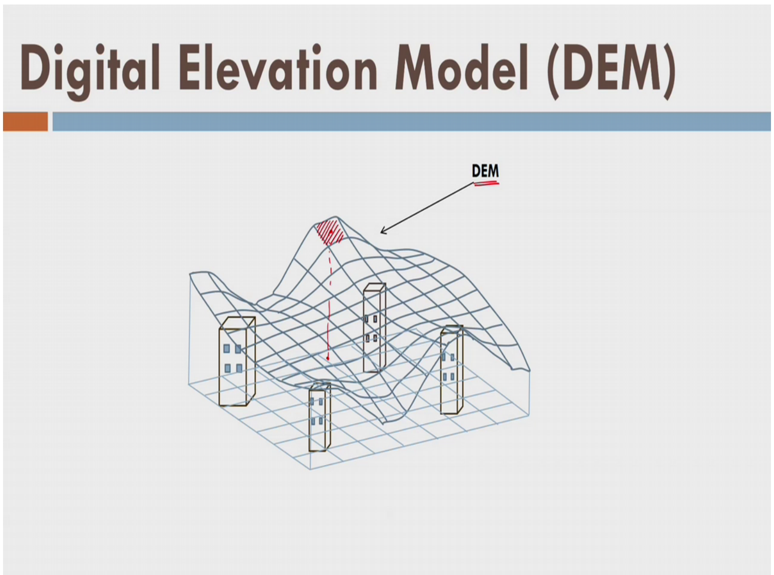

Now, let us look for a real ground natural ground which is curvilinear which is having some slope which is having some upslope and so on. So, this is the terrain DEM representing the that kind of terrain. Here you see one pixel is representing the red value and the central value is on the map here it is representing the XY value. Well, I need not to repeat it again and again, ok.

Now, that remember that each and every cell of the DEM is of uniform size. So, perhaps it is appearing to you that they are of non uniform size here. In fact, they are always of uniform size. So, be careful on that part. It is just a representation on the screen, that is why we are not efficient to draw all this thing that is why we are taking help of this some kind of curved lines and so on, right.

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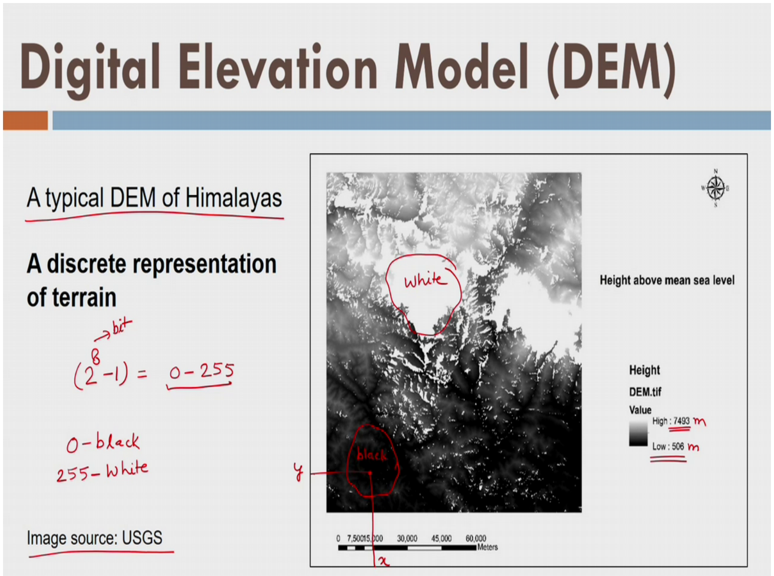

Now, if you see here that a DEM is collection of Z values at given XY location, right. So, I can also represent the DEM with the help of some gray image or gray scale image. What is the gray scale image? Let us say you have an image just like any ordinary coloured image. Coloured image has three bands, red, blue and green. Let us say you have only simple 8-bit screen or 8-bit black and white monitor where you can see the black colour as 0 and white colour as 255.

What is the meaning here, you have some kind 8-bit scale where you say that so many variations are possible. It is bit number; that means, I can show my colours or any variables by these numbers. That means, the whole range of the elevation I will discretize into these 255 or 256 bands. So, that 255 bands from 0 to 255. So, these 255 bands each of these 255 bands will represent certain range of height and now, I will assign each when band one colour. So, the 0 is my black, and 255 is my white and all rest is between black and white they are grey colour. So, according to the shade of the grey will vary according to the height, higher the height; that means, which is or if the elevation is reaching towards the maxima elevation it will colour will go to the white.

So, here you can see this is a white colour here showing the maximum elevation and it is black colour here showing the minimum elevation and the minimum elevation for this DEM is 506 metres and highest is 7493 meter. And, this is a typical DEM of Himalayas, right, and we have taken this image from United States Geological Survey website, just to explain you what is the concept of DEM. DEM is this kind of representation also because at this point this is my X value here, this is my Y value here and this colour value is giving me the Z value, right.

Now, we can understand that DEM is just an representation of X, Y and Z, 3D representation, but does not indicate to any other information, but we have created this 3D DEM using photogrammetry and photogrammetry gives me one more information that is texture and texture is so important for us because it is our natural tendency to identify the features objects with the help of texture.

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Today, I am wearing black shirt, this pen is a black colour, this screen is appearing white to me.

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This mobile phone has some white colour on the screen, well or I can capture the photo using this mobile phone and this photo will be coloured. So, we have different different colours and so on. So, I can straight away say, in this room there is a walk clock here, there is a some lights here, this is an air condition here and there is some wooden piece here and there is a one tablet unit here where I am working on and this is a table here which is of cream colour.

So, all this colour perception we have very strong and this colour perception you know mixes very intelligent in a sense to identify any feature in the field also. I can find out what the glacier, what is the tree, what is the building, what is a sand, what is the brick, what is the mud, what is the water, what is the green, what is blue, what are is some kind of muddy or not all this things are possible with colour only and we should derive the advantage of photogrammetry now, ok.

So, what is what can we do now? Ok, simple thing is that I can wrap up my image over the DEM and that will help me in some sense, but before we do that let us understand DEM with its numerical value or rather with its accuracy limits. So, that it will give us some idea that how can we use that DEM in order to generate some map, a coloured map, textured map. Let us look into that, ok.

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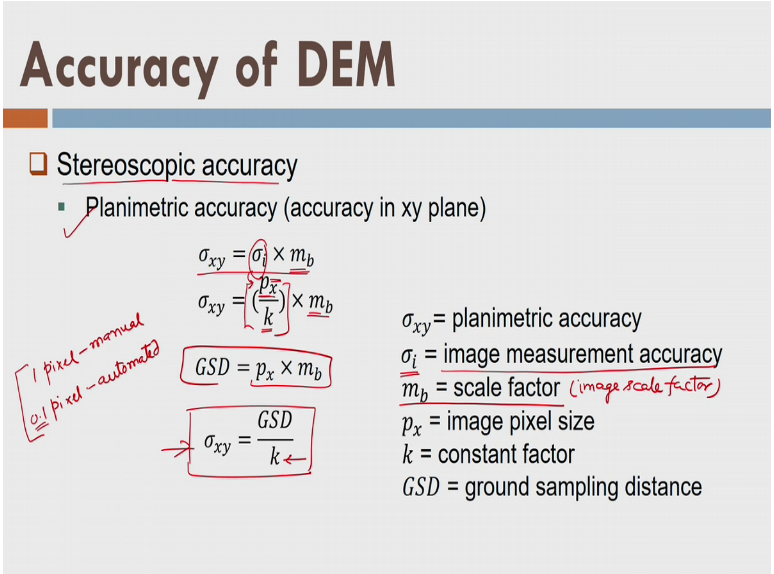

The accuracy of DEM, fine; first of all we have the stereoscopic accuracy remember we have stereoscopic concept and there this accuracy is divided into two parts; one is planimetric accuracy, one is vertical accuracy. So, let us talk about planimetric accuracy first. So, planimetric accuracy is given by sigma xy, sigma i times m b is my scale factor which is nothing, but the kind of scale and now we are defining the scale factor of sometimes it is called image scale factor and which is nothing, but the size of the pixel on the sensor to the size of the GSD on the ground generally we take an average size of the GSD or average size of pixel on the ground, right and the ratio is m b, ok.

Now, we can say the sigma i is my image measurement accuracy. What is image measurement accuracy? That means, when I measure some point on the image I commit some mistake there in picking up the point, that is called image measurement accuracy. And, well, this could be 1 pixel if I am doing manual work this could be as good as 0.1 pixel if I am doing automated tie point generation or automated control point generation or automated point selection if I am doing, right using digital photogrammetry, using some concept digital concept we have we will learn all this thing in the coming lectures on the photogrammetry module only, till that wait this thing.

Let us say so, this is the kind of accuracy criteria, ok. Now, there are many other contributions of the sources of errors that finally gives me some kind of accuracy which I say that it is some kind of you know number of pixels. So, I divide p x my pixel size. So, I am expressing my sigma i in terms of pixels. So, many pixels that means, 2 pixels, 3 pixels, 0.9 pixel or 0.1 pixel.

So, I am just playing with the factor called k such that I can generate 0.1 pixel, 1 pixel or 2 pixel whatever I want. So, my k factor is like that. So, for 2 pixels k is equal to 0.5. So, 1 upon 0.5 is equal to 2. So, 2 times p x I have 2 pixel accuracy like that. Then I have k factor for 0.1 it will be k equal to 10 automatically 1 upon 10 become 0.1 and I will have a accuracy 0.1 pixel like that. So, have I have defined my sigma I like that, ok. Now, if you see carefully p x is a pixel 1 pixel into m b which is nothing, but scale factor is equal to the GSD and as a result I can specify my accuracy planimetric in terms of GSD.

So, how many GSDs are there? It is 0.1 GSD or 2 GSD, 1 GSD whatever it depends on k factor k what is my this factor k is there and that comes by experience that is comes by you know calculations and so on. Now, what is the vertical accuracy? So, I have find out the planimetric accuracy already this one, where the planimetric measurement or the point picking is a measure factor that contributes the error, right.

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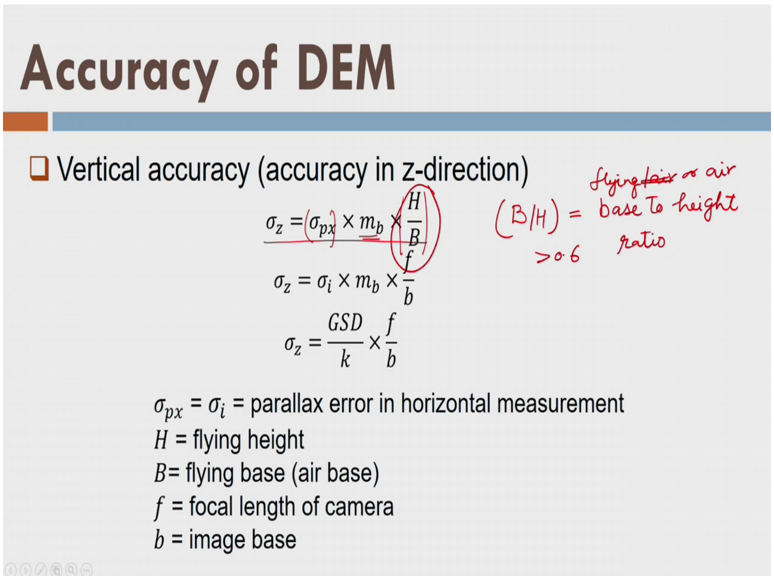

So, this is my expression for the vertical accuracy where this sigma p x is the error due to the parallax which I already evaluated here right and this m b against scale factor and further if you see the vertical accuracy is multiplied with this factor H by B where we call the B by H as my base to fly height ratio or sometimes base to height ratio also is called. More popularly is called base to height ratio remember this my flying base or air base not the image base alright air base, right.

So, now, it is inverse of the base to height ratio. In general base to height ratio is recommended to be more than 0.6. So, if you put it here it will be this factor is going to be more than 1, H by B right, ok. Now, I can replace base H by B by f by b; that means, by focal length to headed two formulas here.

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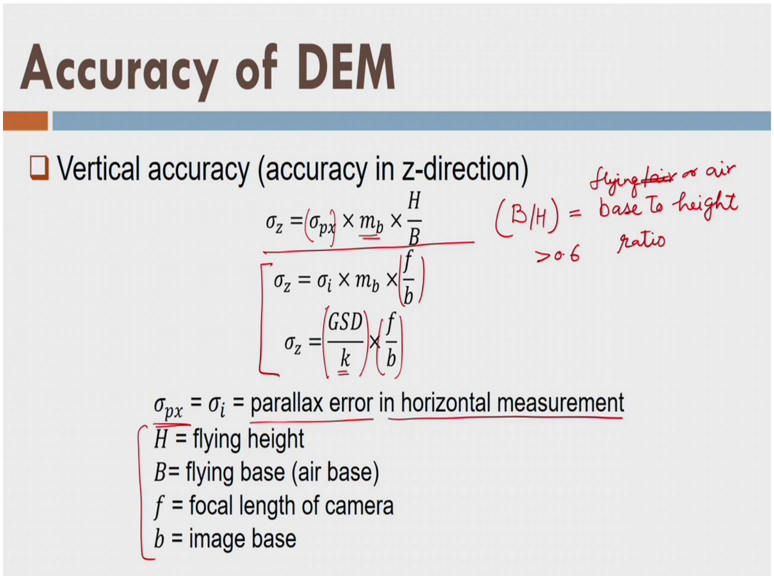

So, focal length to image base and then I can still write this thing sigma Z is equal to my GSD time some k factor again k factor could be 0.1, could be 2 whatever and f by b. So, now, you can see that it is my sigma p x parallax error in the horizontal measurement, fine. I hope you got the idea what is the meaning here that is vertical accuracy now I am calculating ok.

And, these are the rest elements, fine. So, now, you can understand what is the accuracy of a DEM, right each and every point has some and these are just an idea. I can also find out the accuracy of my space intersection process which will be little complicated, but these are very simple process to give me some estimate of the accuracy of DEM.

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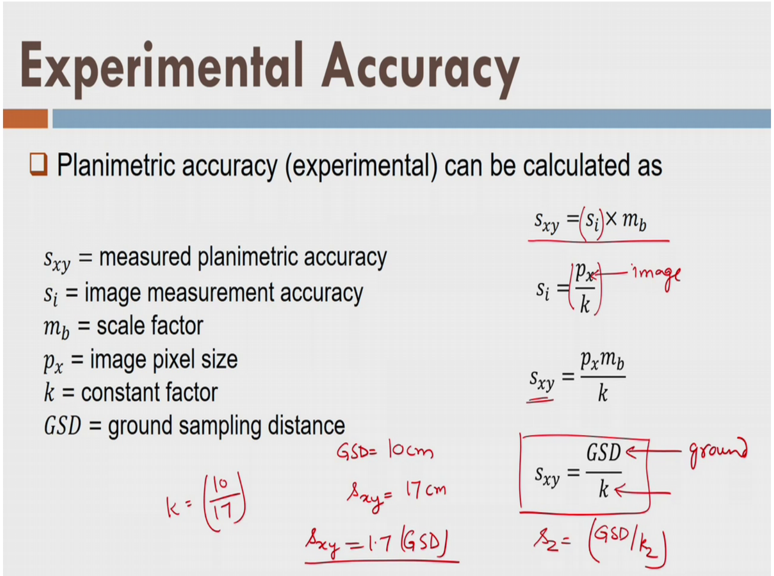

Now, what is the experimental accuracy? So, far we have determined the accuracy by the estimates or by some kind of mathematical calculation. In reality we have to find it in the field also and that is what we call experimental accuracy. In case of experimental accuracy we can say that I am using the same formula again here, where this is my s i not the sigma I this s i is again some ratio of pixel to the k, I already know this thing p x, right.

Now, I can s xy is again equal to GSD by k. GSD I can measure in the field as I measure my p x in the image or on the ground is GSD. So, when I verify or when I validate my accuracy is losing DGPs on a checkpoints. I can say what is the value of k point. So, let us say you find out your GSD is 10 centimetre and you find out s xy is equal to let us say 17 centimetre, fine. Now, you can say what is the value of k? K is nothing, but 10 upon 17, ok. The moment you put it you will get that your accuracies are almost 1 point GSD I hope you got the idea what is the experimental accuracy. So, remember these accuracies are determined with the help of field service RMSE accuracy or whatever, after determining RMSE accuracy we are generating kind of a simple rule for your work.

Similarly, now you are determined the s z also in the field you are determined not only x y you are determined s z also in the field as a relationship of let say k 2 some factor; that means, how many pixels are there in order to indicate that in how many ratio what is the ratio of GSD to the k 2 and so on.

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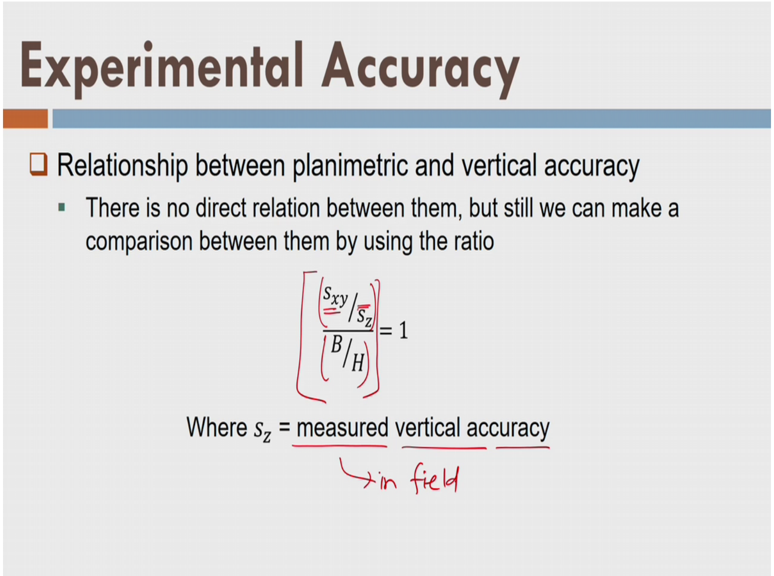

And, let us say that in general this idea is there now the days with digital images that this factor should be equal to 1. My base to height ratio and ratio of planimetric accuracy in field to vertical accuracy in field not the estimated one. In general that is the kind of expectation we have from our work, right. So, s z is my measured vertical accuracy it is not estimated vertical accuracy it is measured in field and verified and validated in the field, right.

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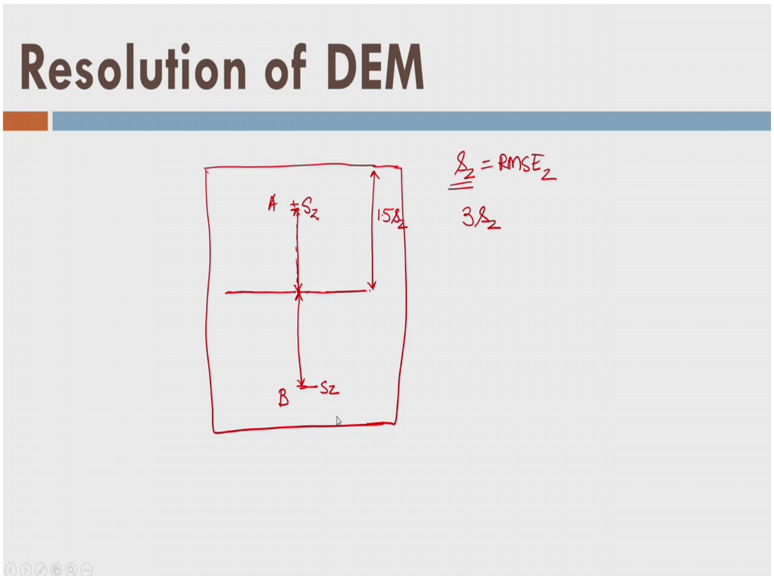

So, now you have calculated the sigma z s z everything. So, what should be the resolution of your DEM, that is surprising question and most of the people make a mistake here. They think let us have the s z accuracy as my RMSE value. So, create a DEM of s z. Now, a computer can always do whatever you like, but it is your physical interpretation that should give you the real idea and that is what I am giving it today. Well, imagine that you have some kind of s z accuracy and this is the point your reporting, that means, this point can be let us say horizontal plane vertically up by S z that is plus and this could be vertically down it is minus s z.

Similarly, when I write s xy it can be on this side or it can be on this side. Now, what to do? When I pick a point I may commit a mistake may be positive or negative and hence you know that we have a limitation here that if I commit a mistake it will be minimum by one pixel I cannot be within one pixel, right because we count 1 2 3 4 number of pixels. So, let us say if I commit by s z; that means, if I am taking a pixel size of s z or the cell size of s z what may happen and if I commit a mistake what will happen? I could be here at this point A or I could be here at this point B, right. How can I avoid this thing? Is any way to avoid? It is a simple way. If I take three times s z as my cell size or the resolution of DEM; that means, instead of one pixel here I take 1.5 pixel here and let us say this side this big size here like this.

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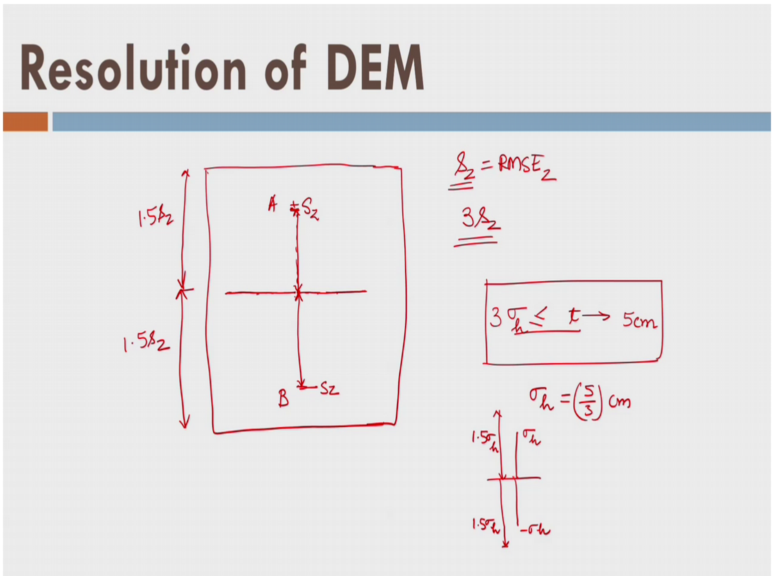

So, this is my 1.5 s z again it is 1.5 s z as a result it is like that. So, now, what I can guarantee you one thing, even if I mistake a mistake to best of my knowledge I can always commit one pixel mistake. So, either I will be here or either I will be here, but I am always within this cell of my resolution of DEM. I hope you got the idea, a simple ideas is there you should always create that three times of the vertical accuracy the cell size or the resolution of the DEM should be minimum three times. If it is 4 times, it is better; in the sense you are most safer side, you are taking more care you know you are giving more confidence to you.

I hope you are very much sure now you should always take the three times of accuracy in order to deliver a product or in order to claim the accuracy of the product, because even by mistake you are here or there you are within one pixel or within one cell size or within one GSD of that product may be DEM or maybe some other product like orthomap or whatever, right ok. This concept was also already explained in the module – 4 adjustment computation when I say that my stigma that error propagated should be less than 3 t and that was the same reason here; that means, this threshold is given by the client or you need this kind of accuracy.

For example, 5 centimetre in height measurement and this is your sigma value that you obtain in the real field or by error propagation if you use some certain instrument and certain given condition. Remember, it was like this I am just correlating the things, they are completely different example. Do not correlate, just to understand. So, this is what we have given there; that means, if you have I am sorry it should be like this time. So, if you have this 3 times is logic 3 times sigma h less than t then what will happen if your client ask 5 centimetre. So, you will have a sigma h suppose if you commit 5 by 3 centimetre then even your plus sigma h error minus sigma h error, but you are always within this one 0.5 sigma h and 1.5 sigma h and this concept is also applicable to planimetric accuracy.

It is not an every accuracy I can say. So, when you report accuracy from the sigma or from the estimate of the error always use this 3 times logic. So, 3 times of the error should be equal to the accuracy. Logic is very simple not a complicated one, and you can now explain to any one, ok.

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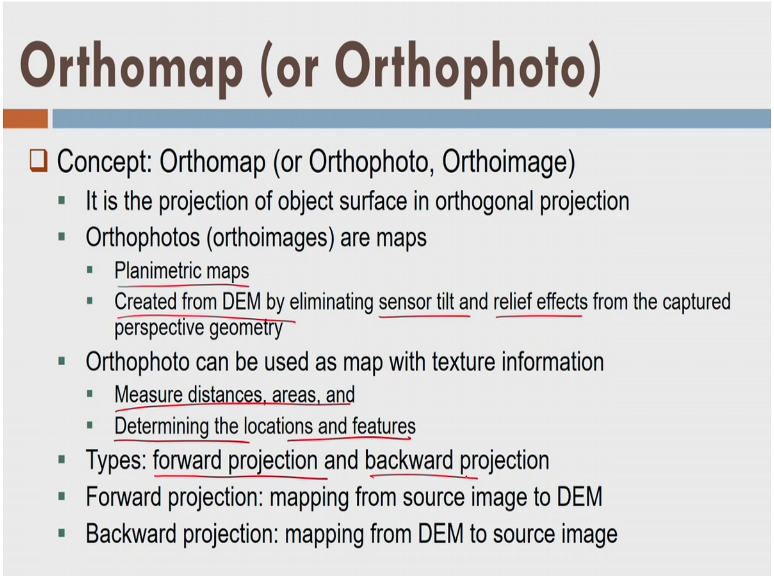

Now, the next product which is my orthomap is generated from the DEM and I already given you one hint couple of minutes before that I want to wrap my image onto the DEM. Why because DEM is just the raw value XYZ does not give me any other information, they just a kind of terrain surface representation, but my image is my perfect texture value and that gives my real sense of the world.

So, but there is a one problem if I wrap the image on the DEM; well, it is good for visualisation, it gives me good feel, but at the same time it has some fundamental problem at the problem is my image is the perspective projection and DEM is my orthographic projection. So, there will be lot of errors by matching the two, but good for visualisation, good for having some feeling. But, even if you could do some call function called image DRAP in one of the some of the softwares, photogrammetric softwares especially in commercial software it is very much available now you can do that. So, if you do that what will happen your pixels on the image will not be at correct place, if you have river it will be on the banks; that means, water is appearing on the banks.

And, that you know that bank is not river, bank is kind of soil or sand it is not river and. So, you face lot of problems may be building top you know having some kind of rallying, but rallying is appearing on the ground or the garden on the ground it is appearing on the building top. So, I need to correct my image in order to create a orthomap which is a textured map compared to the topographic map. Topographic map is also a map that gives me 3D information or contour information with extra information, but it is a topographic map. It does not give me the colour information not texture information, but orthomap that generated from the photogrammetry, it gives me colour as well as 3D information. So, it is called a 4D representation, fine.

Now, in case of orthomaps it is a map I call it xy coordinate only. So, xy coordinate if associated with the some colour information. So, it is orthomap, it is orthoimage, it is orthophoto. When we used to have the photos we use to word used to word have orthophoto, but now we have images we are using orthoimage, orthomap. So, basically we have it is a kind of planimetric maps and it is created from DEM by eliminating sensor tilt and relief affects remember in case of stereopers we have relief displacement. If I remove the relief displacement what will happen building top will exactly coincide with the building bottom in the image and that image will behave like a map. So, we are going to do that part now, ok.

So, I can measure distance and areas and other things and determine the locations and features also that much I can say what is building what is tree and where is building where is my tree location xy, right. It is not surprising, it is not an excellent product I can generate, ok. There are two types of generation process forward and backward process and let us learn this thing.

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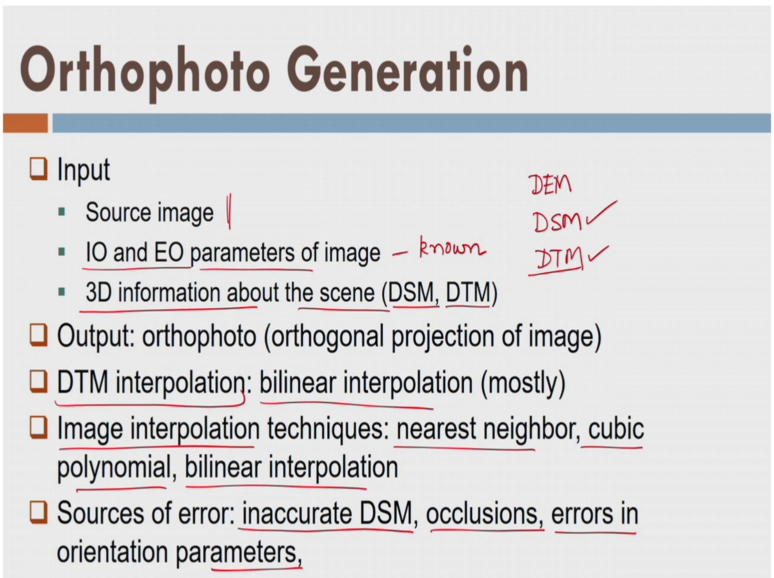

Now, in case of orthophoto generation I have input and input is my source image that I acquired during the aerial photography then IO and EO parameters of image, I assume that they are known, then we have 3D information about the scene that is DSM and DTM.

Yes, I would like to say you two things two terms. DEM is very generic term then we have some quantum called DSM that is called digital surface model. The digital surface model is representation of the surface and surface consists of building, trees, it could be river, it could be sand, it could be ground it could be brick and anything. So, actual surface of the terrain is represented by DSM if I create a product where actual surface is represented that DEM is called DSM digital surface model.

However, if I remove all the superstructure on the terrain which means if I remove tree, if I remove building, if I remove any man made structure or any natural structure which is coming up, not the hills, right. I want to find out basically how my terrain behaves on the large scale. So, I am removing trees and removing buildings and I am trying to see how the terrain looks like and that is called the digital terrain model DTM.

So, now, I can use for my orthophoto generation both DTM or DSM depends in case of urban environment I would prefer to use DSM, but in case of very large scale environment like very big areas may be upcoming town where buildings are not there, I would like to remove the trees and I would like to use the DTM or maybe some kind of a mega flood modelling I would like to use my DTM and not DSM. Why because DTM is going to give me a kind of estimate more or less that is for me.

Secondly I would like to know what is the behaviour of the terrain with respect to the water flow in flood tree maybe could kind of obstruction there, but tree is not going to decide flood, right. It could not dictate the flood it cannot stop the flood, but there is if there is hill, it will decide the flow of the water. So, I would like to keep that hill there, but I would like to remove the tree in the DTM. So, I prepare the DTM from DSM by removing all these kind of structure like building tree and so on. It depends on my purpose for which I want to use my DTM. So, here I can use DTM as well as DSM for the orthophoto generation.

Now, we generate as we already DTM or DSM by bilinear interpolation and for image interpolation we use nearest neighbour cubic or by interpretation. So, what are the sources you see if I have inaccurate DSM DTM we have occlusion and errors in the orientation parameters we will see one by one.

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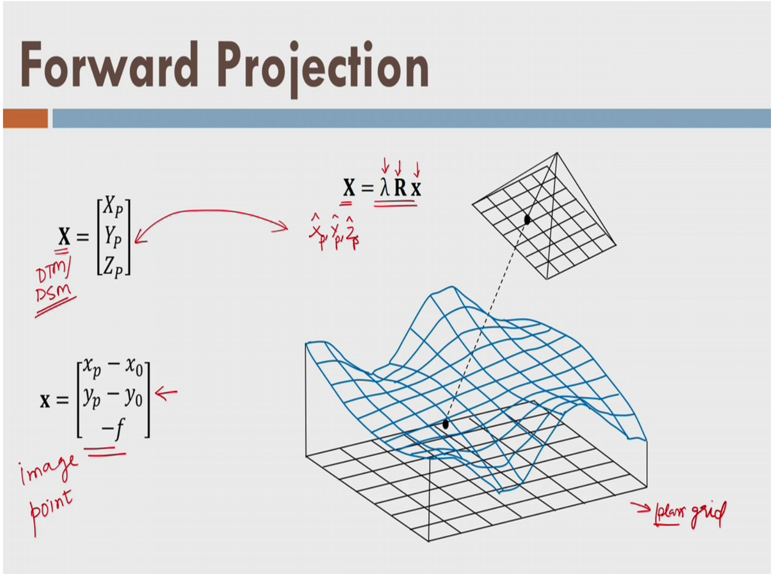

Now, first of all learn: what is forward protection. So, let say or it is my point coming from DTM or I can say DSM whatever and this is my image and understand that I want to convert this image point into orthophoto map point or orthophoto map pixel because that has to provide me color information on map, right. So, let us see this is a DEM, ok. Now, I can say this the grid I am drawing on the plane matrix this is a plane grid on the plan I am drawing the grid here and so it is my image where I am, this is point and let us say I calculate for this point that is this point. I calculate what should be the point on the DTM or on the terrain surface or on the DSM, does not matter all these terms.

So, I use this logic where I use the colinearity equation remember the original colinearity equation we derived where X is my image point, R is my rotation matrix and lambda is my scale factor and lambda will be deleted if I take the ratio of two equations to third equation. Well, using that I will determine my X, Y and Z, ok. Let us say this X, Y, Z is X hat, Y hat and Z hat. Now, I have for point p, they are calculated values I already have this value. So, I can find out what is the error here between the two, right. So, that is process called forward projection air. Forward projection little complicated to understand, but we have another process called backward projection which is quite easy.

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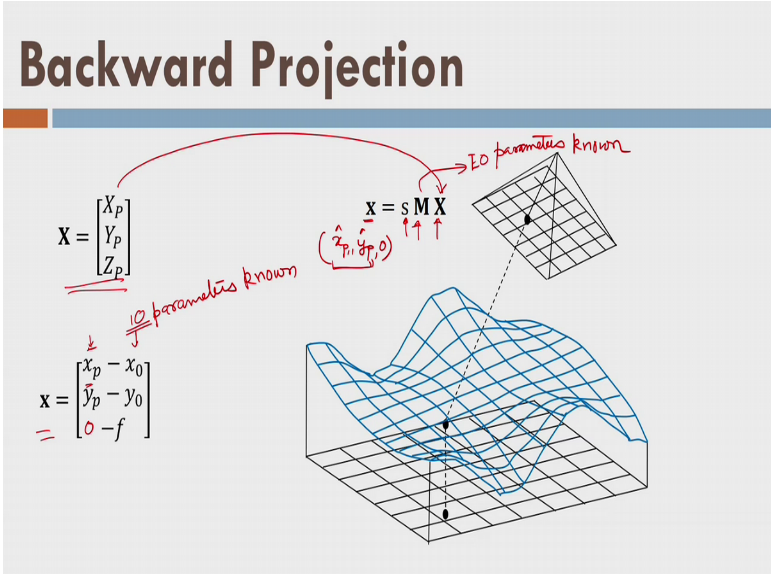

With the same technology on capital X and small x, I am going ahead. So, this is my grid plan grid and this is my DEM, this is the point on the surface of DEM, DSM or DTM. Now, let us say there is a image and remember we already know EO and IO parameters. So, that means, I know my rotation matrix R or maybe the inverse of R, that is m matrix in the co linearity equation.

So, now I project this point from DTM or DSM to the image and I calculate the small x on the image; that means, this is my input capital X here, this is my rotation matrix M which is the function of EO parameters, and these are IO parameters that I already know, here it is using EO parameters as known, right and s is my scale factor, right. So, what happens is the pixel coordinates. So, x p hat, y p hat and we know third term is always 0 like this here 0.

So, we have determined this x p hat, y p hat and here I have x p and y p now I can decide what should be the colour at this location because it is not exactly matching with me x p y p, right and that is a kind of error introduced by the numerical process what we are using here. But, still we have to survive with that, we have to imbibe, we have to adapt that because that we cannot avoid it, ok. So, what how to find out the value of pixel or the texture colour at this location which is an calculated location and which is not same as this one ideally it should be same if there is 0 error, but this is the error.

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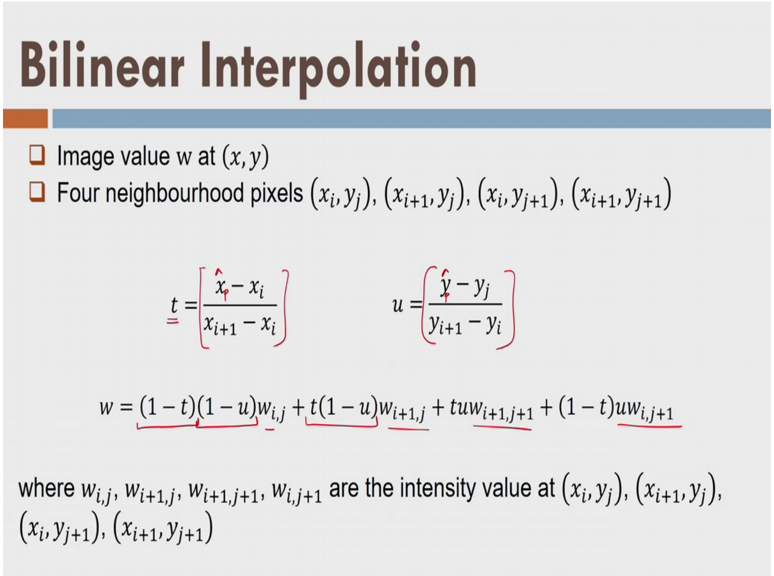

So, we use bilinear interpolation there and bilinear interpolation here I will calculate the t value. So, this is my x p here I can say and it is my y p here hat here, right minus x i; x i is my pixel. So, now, I am calculating these values like this like this and now, I am using this 1 minus t; that means, if the point is away from the pixel what I am saying assign less value to that pixel or I can say let us take the all four neighbours into confidence or let us take the contribution of all four neighbours in some proportion. So, these are deciding the proportions t into 1 minus u 1 minus t into 1 minus u and so on. So, then I have taken let say 1 2 3 4 pixels, right ok.

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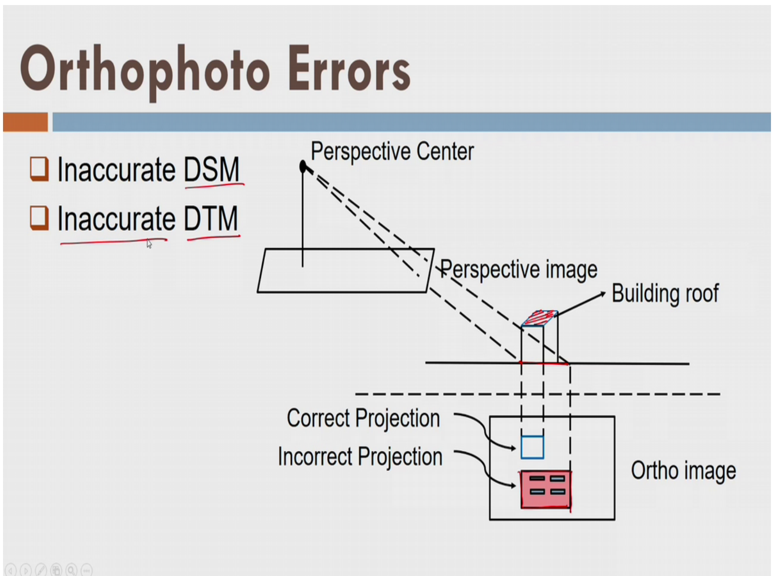

So, what are the errors that are contributed to the orthophoto? So, first is the inaccurate DSM or maybe inaccurate DTM. So, what is that? So, let us say there is a building on the terrain or on the I can send the DSM it should be there. However, DSM does not contain or we have removed it your created DTM and now, you are using DTM you are trying to develop your orthophoto. So, what will happen, ideally this building should be available in my orthoimage. However, because now building is not there and as a result we will assume that this part of the terrain is flat here.

And, as a result since my image has some colour so, it will assign the process of ortho generation will assign some colour to this whole area. But, in fact, the building was this only in the field. So, in the moment I remove the 3D information from my DSM or from my DTM I am going to incur some error and that is because of the in accuracy in the DTM or DSM and this error is basically called the error due to occlusion, ok.

Now let us look into the accuracy of the orthophoto, ok. What kind of accuracy should I expect if I using certain DSM or DTM and certain image to prepare my d ortho image orthophoto ortho map, right.

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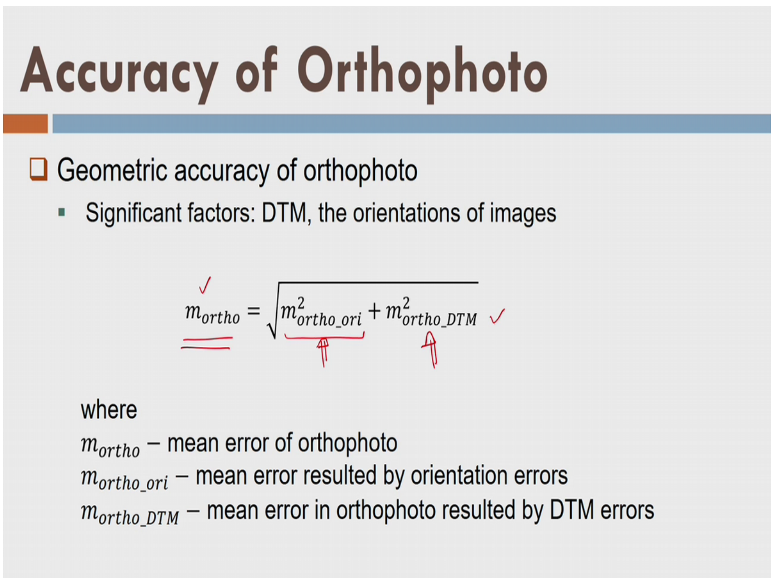

So, that the geometric accuracy of the orthophoto is given by this formula here that is a total accuracy and this accuracy is contributed by the mean error resulted by the orientation error. So, this error is basically resulted by the orientation of the image, right. Because we are bringing our image and making it parallel to DEM. So, basically we are adjusting our image onto the DEM and that the change in the orientation of the image itself creates this error, alright. So, this is kind of numerical error and that has to be estimated by experimentally or by some numerical process, alright.

Now, there is a another error that is contributed by the DTM, alright. So, whatever error in the DTM is there that is basically giving the, this kind of error here it is written m ortho DTM. And now, since two errors are independent to each other what we are doing they are making them square adding them and making the under root and finally, we are estimating the total error here. Remember, this is a kind of numerical error or we are need to estimated by numerical process or maybe by experiments. However, there is some expressions given for the errors caused by the DTM, ok.

And, here there are two ways to express this error; one is the mean error or one is the point error. That means, if I am considering the overall terrain that I want to find out an overall performance of my orthomap overall accuracy of orthomap in that case what will I do? I will take an overall idea or overall variation of the terrain or overall variation or overall error of the DSM or DTM I will consider that error of DSM or DTM to the overall error of the orthomap, alright. So, that is I am just reporting the error of overall product that is my mean error there. However, I can also consider that what is the error from point to point.

That means, if there is a building so, if I take one corner of the building and try to what is it is position on the map or ortho map. So, in that case I am trying to estimate the point error for that building corner alright. So, let us look into these aspects first.

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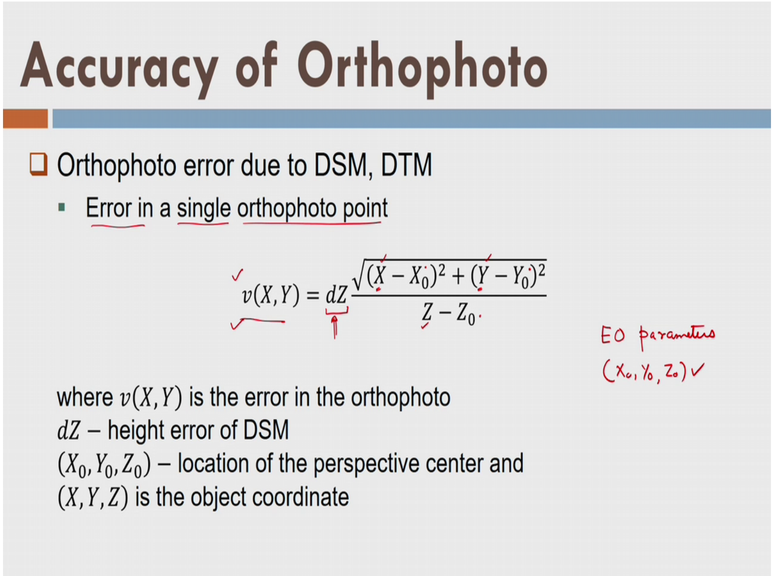

So, error in a single point let us say right as a given example of building corner it is given by this here you can see that, what is the dZ? It is the height error of the DSM or my DTM and this X and Y they are basically the object coordinate or let us say the corner of the building has X and Y coordinates, right.

And, similarly it has Z coordinate alright. So, what is my X 0, Y 0 and Z 0? They are basically the location of the perspective centre, alright, by the interior orientation or the by EO parameter as I determined the EO parameters, right. So, they are nothing, but my X 0, Y 0 and Z 0 and remaining parameters we are not considered here, alright. So, once we determine the EO parameters I come to know this since I am observing point on the ground surface so, I also know that xyz of that coordinates of that point, right. So, let us say building corner and then dZ is an kind of error contributed by the DSM or the height or the elevation error.

So, this is the way we estimate the error in the orthophoto and that is the point error, ok. So, that is not an overall error. So, I can estimate this point error at each and every point by putting this value of X, Y and Z again dZ is coming from the DTM, ok.

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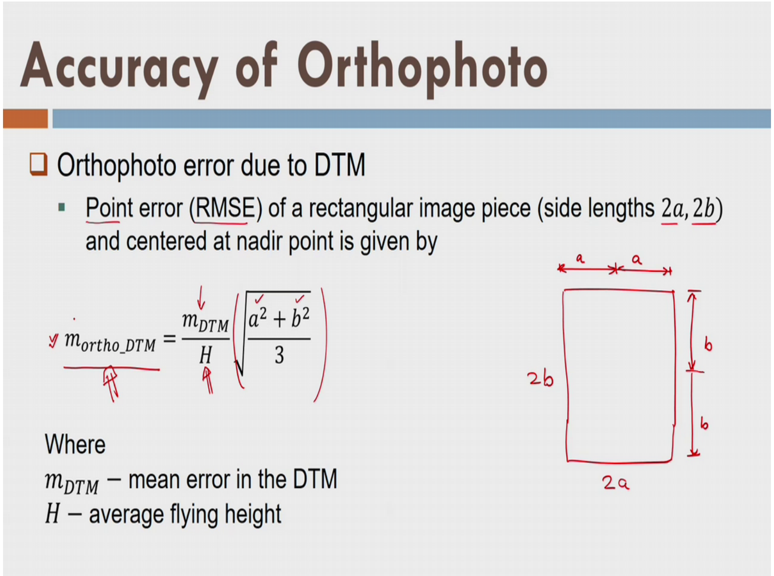

So, next is the orthophoto error due to the DTM, but now we are estimating the error or the RMSE error or we are writing it here point here, but still it is RMSE; that means, we can say that each and every point of the orthophoto is suffering or having this kind of error. And, that is why we are saying that it is and kind of mean error over the whole image.

And, now imagine that we have a rectangle image which has a side 2a and 2b which means let us say this is my image of rectangular shape let us say like this. So, I can say it is my 2a and it is my 2b, alright; that means, b and b here and we have a and a. similarly we can divide into two part a and a here, alright. So, with this I can I am here writing this expression and that is the error in the orthomap contributed by the DTM, right. So, again I am saying that this is a mean error here of the DTM, it is not a point error, right.

And, then if I multiply with this factor I will have the estimate of a the ortho map error contributed by the DTM. But, an overall DTM performance or overall or say RMSE of the DTM, alright. So, now, we are having an error in the orthomap and this estimate is basically applicable to the whole product, alright and which is of this size 2a by 2a. I hope that you got the idea and again I am saying here H, what is the H here? It is not again the point estimate of the flying height it is basically average flying height.

So, this error basically indicating an average idea or the overall RMSE of the orthomap product, alright; so, now, we again we have to go back after estimating this thing and we have to estimate the overall error where we need to put the orientation error also, ok. As we have said already that orientation error between the image and DSM has to be estimated by the experiment on numerical way. However, we have done estimate of the error in the ortho map that is contributed purely by DSM or DTM, then we have given the expression here one is point estimation and one is the overall estimation or the RMSE of the for the whole given area.

So, that is the idea about the orthomap accuracy and that is an estimate. Ultimately, we have to go in the field and we have to find out that what is an overall accuracy is there. So, what we will do, we will take some reference data with GPS and we will take some data from the estimation and then we will try to compare them and that is the way we find out what is the error in my orthomap locations of different different points or features.

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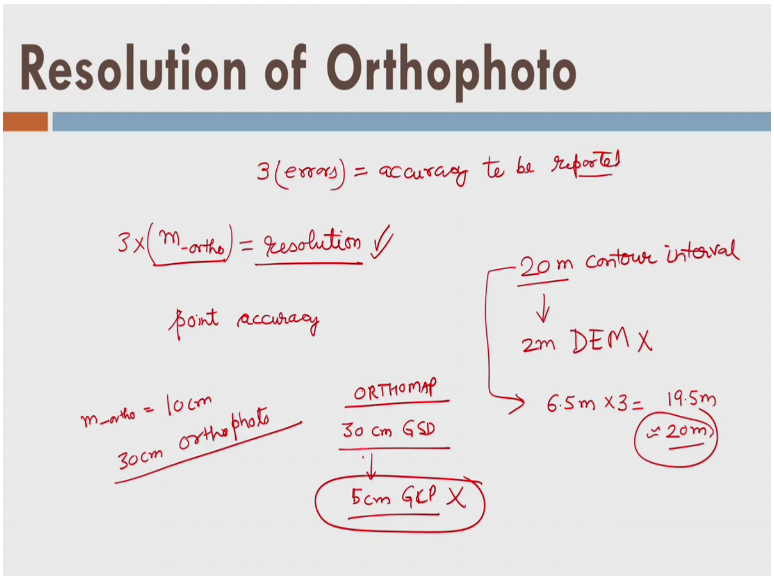

Now, what is the resolution of orthophoto? The resolution of orthophoto is very very simple idea, again the resolution of DEM or any identity or any entity you have remember that errors is given then create 3 times of error and that your becomes accuracy to be reported. I am giving one simple example remember we have 20 meter contour interval on survey of India. Many of the scientists, many of the researchers commit many mistakes here. They create from this 20 meter contour interval some kind of 2 meter DEM which is absolutely wrong, not acceptable.

Is it you should understand that, why it is 20 meter was decided. Because there was some accuracy of this level 6.5 meter or may be 6.66 meter and as a result if you multiplied by 3, I will get around 19.5 meter or you can say approximately 20 meter. So, that was the reason and old times when we are survey of India toposheets we have 20 metre contour interval here. Similarly, suppose you find out what is the accuracy of orthophoto, m ortho may be a one point accuracy whatever or could be let us say point accuracy whatever, right.

And, now we want to generate you are calculated it and you want to generate or you want to re-distribute or you want to re-simple your orthophoto or you want to generate the two orthophoto which is accurate enough or whatever accuracy is there it is really giving that accuracy. So, what will you do now multiply it by 3 and make it equal to resolution and re-simple your orthophoto create this kind of resolution it may not serve your purpose in the field, but at least it is very very accurate, ok. So, whatever purpose you can serve with this kind of orthphoto, this orthophoto is best for that purpose.

If you have let us say 10 centimetre is m ortho. So, you generate 30 centimetre orthophoto, right and with this 30 centimetre orthophoto whatever you can do, do it in the field; that means, your map is of 30 centimetre GSD. So, or ortho image is of 30 centimetre GSD you can use this ortho map of 30 centimetre GSD for feature identification on the ground surface very easily. For example, what are the faces of a glacier or what are the you know the banks whether banks are vegetated or not, all this kind of stuff you can do. But, do not do one mistake collecting 5 centimetre information or 5 centimetre GCPs from this, this is an absolutely wrong idea from this ortho map.

So, here we stop we finish and I can say today that we have learnt completely what is ortho map and DEM or DSM or DTM. With this now I can confidently say that you are not an expert photogrammetrist, but at least you understand what is the photogrammetry. In the next lecture we are going to understand some of the operations or some of the logic or some of the mathematics or some of the photogrammetric procedures that are purely related to digital images and, that were not popular when there was no digital photogrammetry. Because, those processes were not invented rather and that process is digital image matching and that using this digital image matching we can now compare the two images. We can find out the automatic points using digital automated processes. I need not to pick the point manually. I can do it automatically.

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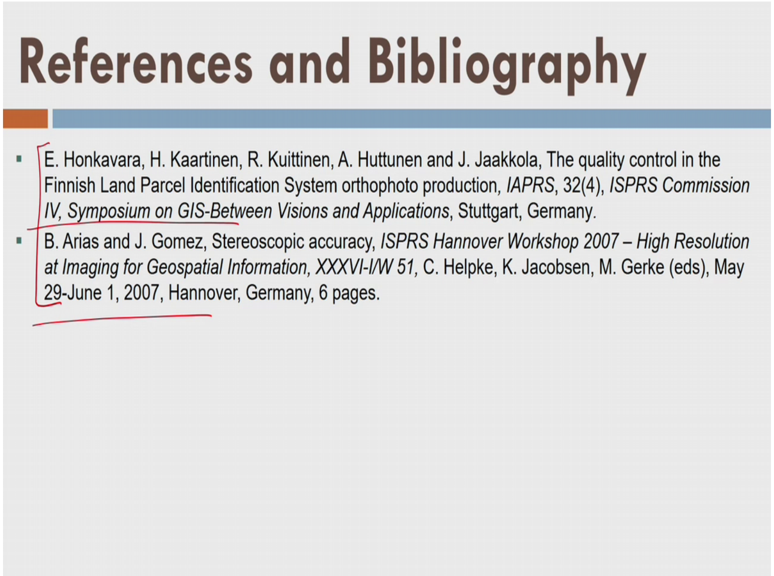

These are the references we have referred for this lecture and if someone is more interested can go to these one, they are good asset or I can see they are good papers good references for a knowledge also.

Thank you.