Global Navigation Satellite Systems and Applications
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Lecture – 01
Introduction to Global Navigation Satellite System (GNSS)

Hello everyone and welcome to introduction to Global Navigation Satellite Systems. In this course, we are going to discuss about different navigation systems, which are there in operation in space. We all are familiar with the initial systems like global positioning system GPS of US, NAVSTAR and later on many new systems have been developed, still few countries are developing their systems and a lot of you know, augmented systems are also coming.

So, during this course we will be discussing all those in details. Basically, as you know that it is for positioning and this has been important since ages that one need to know where I am standing on the globe? And you know, the thinking of that I am may be lost because of lack of position, was always a problem and then in past like Christopher Columbus.

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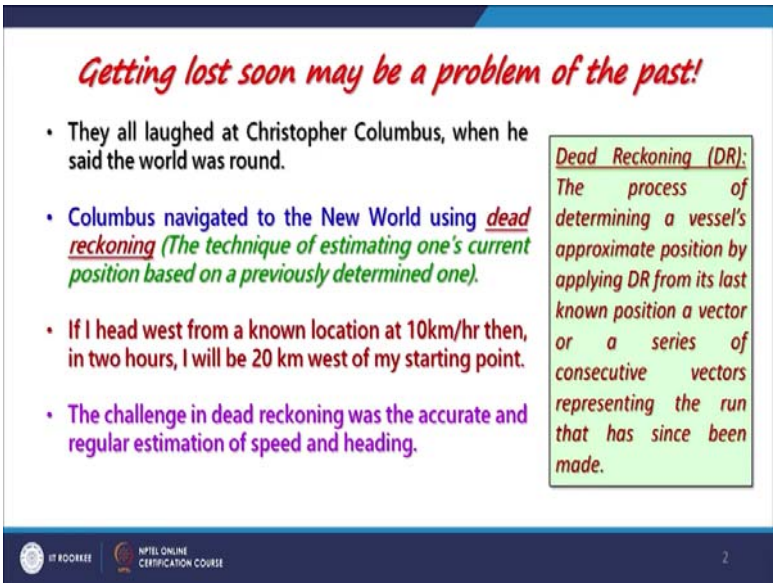

When as per his understanding, he said that the earth is round, people laughed on him because this is what the initial assessment was there, but before that some people used to

think that earth is like a plate or something, but after his, you know several adventures investigations, he found that earth is round.

Now, he also because when he was doing all this navigations and other things, they used to use the navigation system not like today which we are having very sophisticated one, the one technique which is called the dead reckoning. Under dead reckoning, basically is to estimate once current position based on a previously determined one and this is how they used to, you know navigate in the sea and explore the world. The process basically, in this dead reckoning, the process of determining a vessels approximate position by applying DR, that is dead reckoning from its last known position. A vector or a series of consecutive vectors representing the run has since been made.

And this is how the navigation in the sea started and later on some equipment also started coming and then finally, we are having now these satellite based navigation systems.

So, this is how that dead reckoning use to be used that if I had west from a known location at 10 kilometer per hour, then in 2 hours I should be at, in the west for covering 20 kilometer starting from my point. So, one need to note down the speed and time and by which then vector used to be drawn and this is how the position used to be estimated. Now, thus word which is being used here over the term is estimation because even the navigation systems which are satellite based navigation system, there also we say that the position estimation. This is how the positions are estimated whether with the old system of dead reckoning or new systems like this.

And as I have mentioned that this is a important question where am I? Many times it is required and this question which is very simple sometimes can be a matter of life and death as well.

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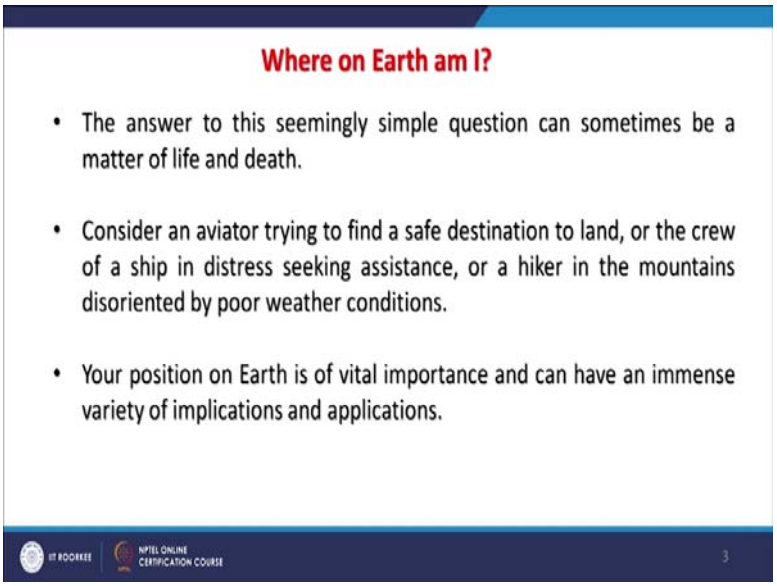

So, if somebody is flying then it is very important, a quick assessment of this location estimation is very much required, somebody is distress or lost somewhere maybe on glaciers or some other dense forest, then they also require the position. So, the position has always be important to know where am I on the earth. this question was expected every time.

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Now, we go in this that there are various technologies are coming for a navigation and which are all space based technology which I am talking except with some ground based augmentation systems are also there, which we will be also discussing.

You are familiar with the very common word which we use the GPS that is Global Positioning System which is basically US develop first this technology as in name of NAVSTAR or before that SDI, Strategic Defense Initiative which was a part of a star war between USA and former Soviet Union, but GPS is one of the systems of GNSS. So, a new term which we should be using rather than solely GPS, is the GNSS because GNSS includes GPS and other systems like BEIDOU of China, GALILEO of Europe or GLONASS of Russia, an Indian systems has also come. So, if a same device, if it is capable of receiving signals in multiple channels, then the same receiver can receive signals from various such navigation systems.

And of course, if your device is capable of receiving signals from various navigation systems, then this position estimation is going to be very accurate. If we take the data only from one navigation system say for example GPS that we may not get very good position estimation. So, now the devices are there even in a standard smart phones, we are finding that the receiver which is inbuilt in the smart phone are also capable of receiving signals not only from GPS, but other navigation systems as well.

So, it is a better now a days, for a navigation we should use word GNSS rather than GPS because now it is no more only GPS. And as we know that these satellites are orbiting around the earth and they transmit the data and our receivers basically calculate the or estimate the positions so, that we will be also discussing in a later part of this lecture or in other lectures also.

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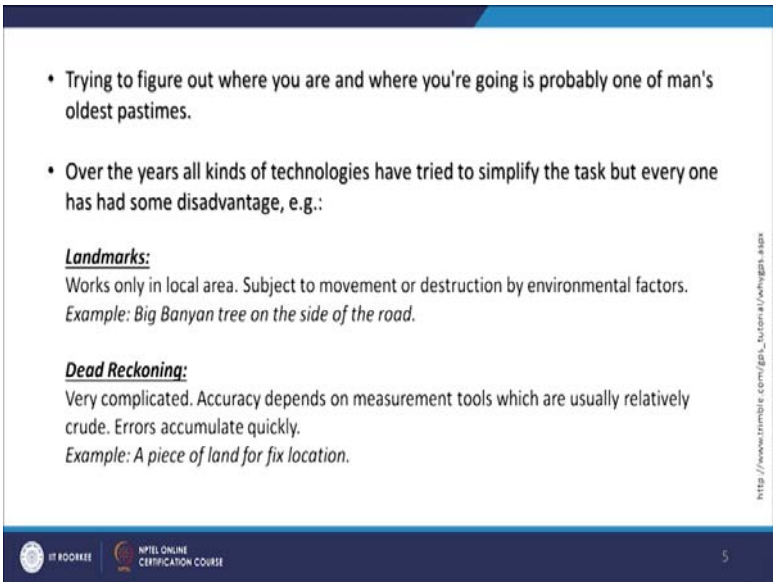

As we have been discussing that the question is the where you are and where you are going to is probably one of the man's oldest past times. Since ages, we have been always looking answers to these questions and we want a answer of these questions that where am I? Where am I going or heading? Very quickly and that is why we would like to have not only quickly, but also their position estimation has to be very accurate. If there are areas, where we are having landmarks so, we can locate ourselves rather relatively easily, but there are areas like if somebody is in a desert area or in some are dense forest area where we do not see the landmark.

Then the position is very much required and it is hard to, you know estimate without using satellite based systems. So, that is what it is very important that if land marks are there, fine otherwise dead reckoning as mentioned dead reckoning was more being used in the earlier in the sea navigation and then of course, using the modern systems now things have completely changed.

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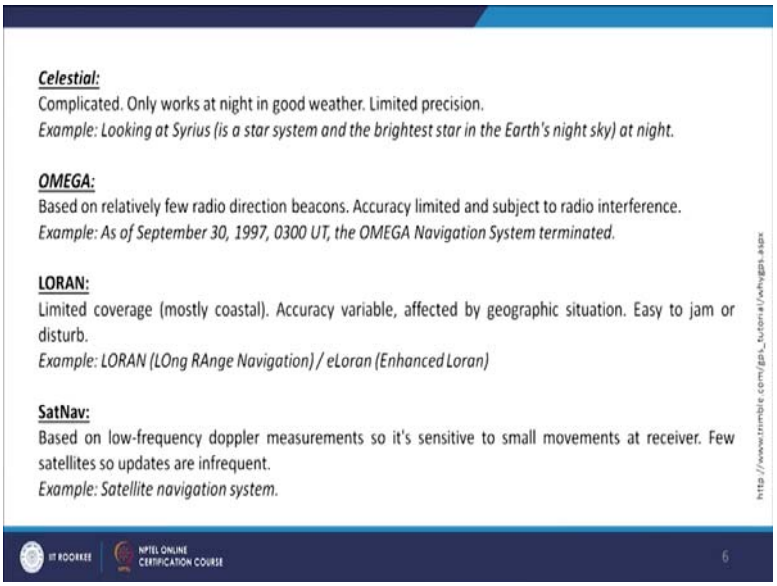

There were some other methods like celestial method which was complicated only works in the night which was based on the basically stars, but if you are having clouds then one had a lot of problems with that's one and then a system came also is the omega which was a radio direction beacons, but again in an open sea, if you do not have the signals from these beacons then again position estimation was very difficult.

So, in past you know like earlier, people started developing new and new methods of estimations, but they were not as accurate and not available all the time. So, people has always been looking a navigation solution or position estimation solution which is should be available for all parts of the world, day and night in all weather conditions. And these modern navigation systems which we are going to discuss in this course, are capable of providing signals around the clock in all weather conditions. After omega this loran also which was there, but accuracy was very well and it was affected because of geographic situation and these we have vulnerable from jam and other disturbances also.

So, this is long range navigation or eLoran, a later on the system came eLoran, but again the SatNav basically a satellite based navigation and this has completely change the scenario of a position estimation and which is based on the low frequency Doppler measurements and it is so sensitive that a small changes in the receivers position can also be detected and these satellites sent pulse or signals every second. So, your position can be estimated very quickly and very accurately. So, these satellite based navigation

system is now very popular and this is what the GNSS. They call because many such systems are available at global level and that is why we use the word global navigation satellite system.

Now, I have used a term Doppler. So, very quickly I will go through these few terms that the ….

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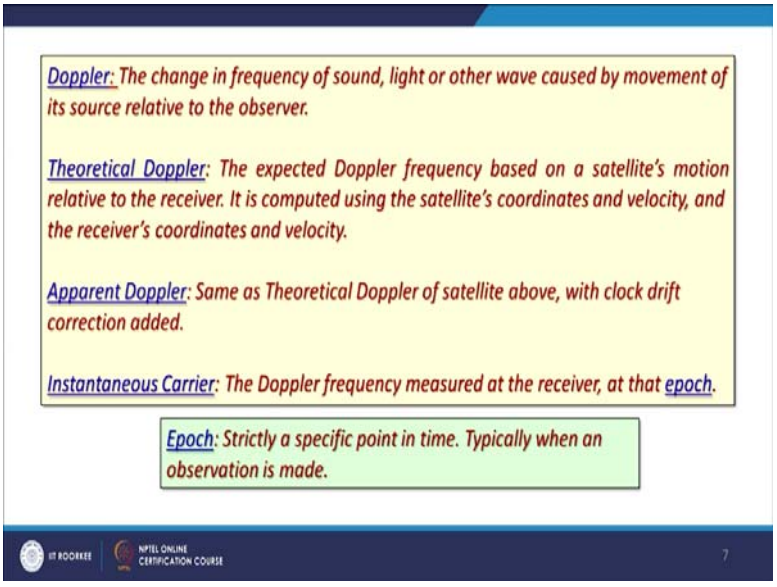

A Doppler is basically change in frequency of sound, light or other wave caused by movement of its source relative to observer. And we know as in the simple physics as Doppler effect, that if vehicle is coming towards you then the noise of or sound of the siren is going to be different. if it is going away, then it is going to be different and it is due to the Doppler effect. So, you know thus these background about the navigation, the background is of course the fundamentals of physics and there is another term which is being which will be used in theoretical Doppler that is the expected Doppler frequency based on satellites motion relative to receiver.

Why because these satellites are all the time you know, moving in their designed orbits. So, you yourself or receiver might be moving and the same time satellites are also moving and therefore, some estimation are done and that is through this theoretical Doppler. So, this is a computed using satellite coordinates and velocity at what speed the satellite are moving. Most of the time they are moving at a constant speed, but some time they might be some variations and receiver coordinates that is what if I am holding

receiver then my position or receivers position and velocity if I am having a receiver and moving like I have fitted in a car then the velocity will also play a very important role.

And based on this movement, the speed or my velocity can also be estimated very accurately. There is another term which is also used is apparent Doppler which is same as theoretical Doppler of satellite above, with clock drift correction added because as we will discuss in detail as, but initially at this stage I can say that all these satellites are having synchronize atomic clocks. So, that because basically in these systems as we will learn in near future that when they sent the signal, this signals are time and dates stamped and when it reaches, then the delay time is basically these are ranging devices. So, the time taken to reach to the receiver will give you the distance. So, this is how the importance of time because you are getting signals from various satellites to estimate the position.

And therefore, all the satellite should have the same timing and that is why I have use word synchronize atomic clocks, they are having and their use. Another term which we will be using is a instantaneous carrier that is Doppler frequency measured at receiver or at that epoch. And epoch is strictly or a specific point and time typically when on observation is made. So, because these systems, the GNSS systems are all the time transmitting the data and whenever receivers are on, they can receive signals and they estimate the position.

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So, worldwide position and time determination system basically that includes one or more satellite constellation, aircraft receivers and systems, integrity monitoring, augmented as necessary to support the required navigation performance of the intended operation.

This is a current definition, it might change in future because new systems are coming, new augmentations are coming and new concepts are also coming which we will be discussing also in this course. So, basically when we use the word global that means, these positioning system should be available for any part of the globe. But now though we are using word global, but people have also developed or some countries have also developed regional navigation systems like a GALILEO of European space agency which is a regional system. Our this navic or IRNSS which is Indian Navigation System which is also a regional one, it is not global. Because these system have been designed to focus only like in Indian system has been designed to focus only in the Indian subcontinent or in little bit in neighboring countries.

So, though still there are global systems are there like a NAVSTAR which is GPS, a GLONASS which is Russian and BEIDOU which is Chinese also global so, but in this we are including regional in our discussion also we will be including regional as well as global navigation and all these are satellite based and in order to improve further the accuracy, some ground based augmentation systems are also have been developed, are being used and some we will be discussing, a space based augmentation are also possible and ground based. Ground based Indian example is GAGAN is there or a SBAS technology is also there. So, that is will also fit here. So, if I again go through the definition of GNSS that is global navigation satellite system, a worldwide position and time determination system that includes one or more satellite constellation.

At least now our receivers, an ordinary receiver inside a smart mobile can receive signals from 3-4 constellations like if I go outside of this room and switch on my mobile and some app which can access the data through these satellites constellation, then I will be getting signals from of course, from GPS that is NAVSTAR. I will be getting signals from GLONASS Russian and Chinese. And one SBAS signals are also we are getting which is through the geostationary satellites. So, multiple systems are there, they are possible; they are being used to estimate the position. Aircraft receivers also, they use all

these navigation system all modern aircrafts now a day are fitted with the GNSS navigation systems and a very accurate positioning is being done.

System integrity monitoring even in the aircrafts sometimes if you travel you will find that they display the position of where your aircraft is flying and in the background you might be having Goggle map or some other satellite image. So, that at the position of your aircraft which is a live or it is getting updated every second is coming from all these navigation system. So, it is not necessary that you has to, only you will get position if you are flying over India, it because these are global. So, any part of the world you go, you will get the signal and system integrity monitoring because whoever develops these systems, they have to maintain the integrity of the system.

So, they keep monitoring and if there are, because after all the satellites are orbiting objects in the space. So, sometimes they drift from their designed orbit. So, they have to be brought back in on the on the design orbit and this is all done through the monitoring and other operations which general public or simple users like us, we need not to bother, but those who are maintaining such systems they have to bother about the integrity and they monitor and maintain the integrity of such systems. Augmentation as I have already mention, satellite based augmentation like SBAS and other or ground based augmentations like GAGAN or some in different countries are having which we will be also seen.

And basically the intended operation here is position estimation.

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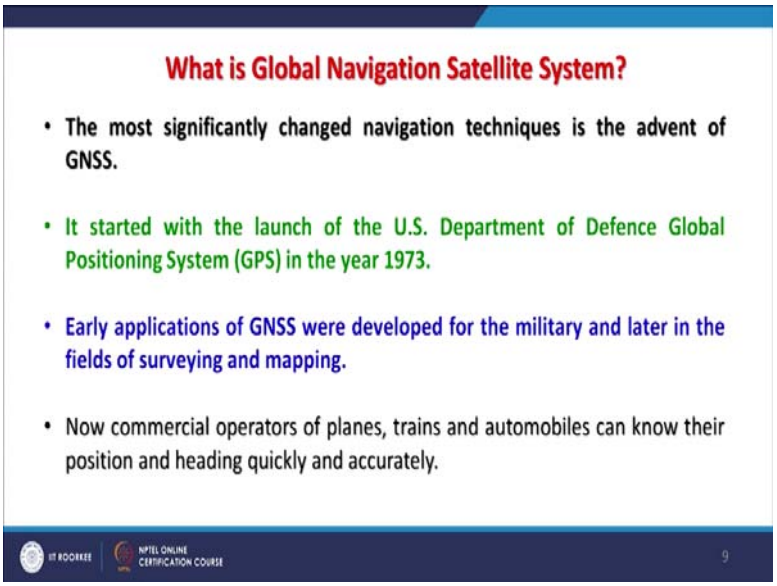

So, what basically has happen, the most significant changes which has occurred in this navigation based, as I mentioned that the first time because if we go in the background or development of such navigation system as like remote sensing is started in the Second World War and people thought that use this technology to defeat the enemy. So, the GPS or this GLONASS, they were also basically of cold war between US and former Soviet Union. Both we are developing simultaneously these navigation systems for to put on the missile. So, that they can hit, these missiles can hit the target a very accurately for which they wanted to have some navigation systems and these two countries developed, one US develop this GPS or NAVSTAR under the program of SDI.

And a parallely Russians also developed. Later on, they too brought to the civilian use as US did. So, in 1973 this development started in US and then early applications where basically these initially given like in that Iraq Kuwait war, first time US army people in the year 1991, they started using these GPS receivers and later these were released or the permissions were given to the civilians. So, people have started using for surveying and mapping. Though their size and capabilities and accuracy as compared to today was very poor, but this is how the technology started and develop. Now many commercial operators are there. So, they are using these navigation devices even our in cars now also through mobiles, smart phones or navigation fittest in our car.

So, we can use these of course, aircraft started using first and trains, automobiles and the background you are having the map so, you know where exactly on you are and if you are driving you know exactly at what speed you are driving. And then once you are having this location and updated location which is being updated every second in the background, you are having a GIS map then lot many things, a lot many information can come to use so that we will be also discussing later on. People use also or in the field as geologist or civil engineers, we can use handheld GPS or GNSS devices including now smart mobiles and can get our position or the answer where am I very quickly in just a few seconds, and with the accuracy of this handheld receivers maybe in few meters.

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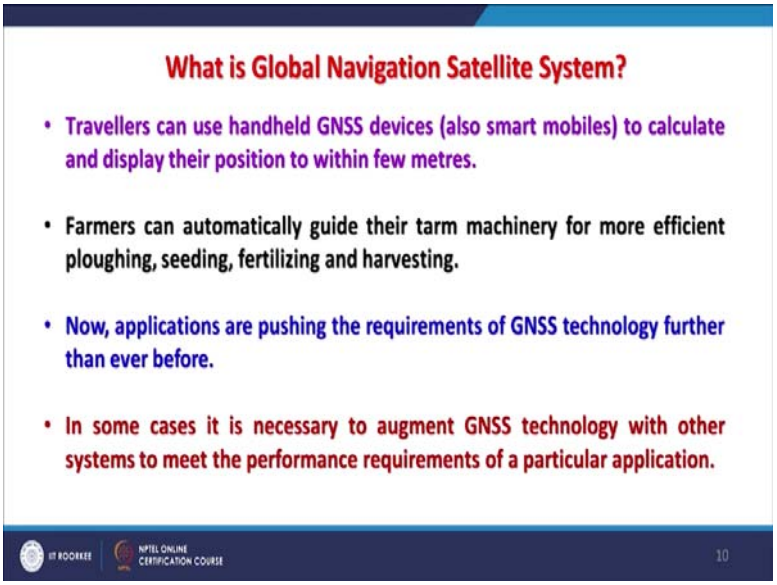

So, two-three meters nowadays with that accuracy it is possible if you are in open area. People have also started using in farming, in agriculture. How to use these farming machinery for very efficiently, for plant seeding, fertilizing and harvesting. So, this entire process, where the one agriculture plot is very large maybe of 100 acre or 200 acre, where it is difficult for farmers to do such work.

So, if they can employee this GPS or positioning system, automatically guided machinery can be used there and as a new systems by different countries are being developed, as more accuracy we are getting, accuracy estimations or position estimations we are getting, more new applications are also coming. So, those will keep coming many of these we will be discussing in due course of this course. It is necessary to augment

GNSS technology with other systems, maybe ground based, maybe satellite based and others and of course, people are trying to use to improve, basically position and as quickly as possible.

So, two things are there because they have a one technology which is also came which is differential GPS and post processing; that means, you do the field survey, later on you come in the lab and then do the post processing then only you will know the accurate position. So, rather than knowing later on, everyone wants that when I am in the field or outside I know, I would like to know exactly where am I as accurately as possible as quickly as possible.

So, that is why all these new technologies are getting integrated in this GNSS technology. As we know that there are constellations; constellation means here

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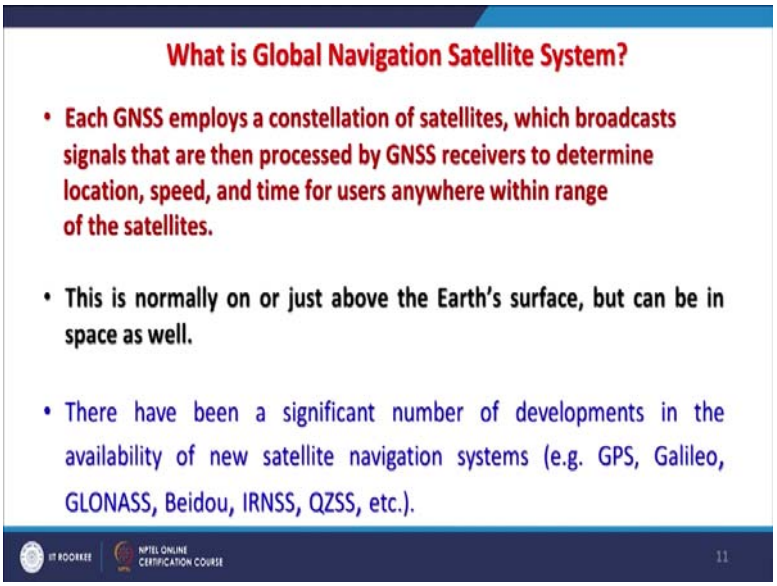

the network of basically satellites, all are moving in space and they are basically enveloping the earth at a very far distance, and as also mentioned that these satellites broadcast their signals and this signal is basically contains the ID of the satellite and where am I, the position of the satellite and at what time the signal is being dispatched. And once it is received by a receiver then the position estimation is done.

But it is not based on just signal from one satellite. The receiver should receive signal at least minimum for horizontal positioning, at least from three satellites and for if we want

the z position also, then from four satellites at the same time then only these x y and z positioning can be estimated. So, these receivers, basically they are having a small computer inside. So, they ,you know process the signals which are coming from satellites every second getting updated and after processing you get the location estimation, you get the speed if the receiver is moving and time.

Time is also important and the time which is coming through the satellites as I mentioned they are having atomic clocks very accurate. So, thus only there are some applications where people are using only time from these constellations. So, that is another very interesting thing which we will be also discussing. It is not only that we get the position only on the surface of the earth, but we can get position in space as well like this aviation sector, they are using though they are not in space they are quite near to earth, but if you go in deep in space, probably you can get signals there also and position estimations is possible.

And a lot of development as I have already mentioned that you are having initially the GPS came, then GALILEO, then GLONASS and then BEIDOU, IRNSS which is our Indian system it has been renamed as a navic, QZSS which is a Japanese system. So, here GPS is truly global system, GALILEO is complete regional system, GLONASS is a global system, BEIDOU is a global system, IRNSS, QZSS last two are the regional systems.

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So, there are, you know all these navigation systems are there in some parts of the earth like if I am located in India, I may not be getting signal from GALILEO which we do not get, I have checked and we get the signals from like of course NAVSTAR GPS, we get the signal from GLONASS, we get the signal from BEIDOU. IRNSS in future, we will be getting signals and in addition to this, our receivers which is the single frequency if we go for dual frequency, we can get more signals from other augmentation systems, but even a single frequency receiver is capable of receiving signals from like BEIDOU, GPS GLONASS and SBAS which is coming from a geostationary satellite.

Now, these satellites or these constellations are at different distance in the space; their constellation, their design orbits are completely different, but still our receiver can receive signals only thing now we require more smart programs within our receivers. So, that they can process the data and estimate the position as accurately as possible. So, like GPS, our NAVSTAR which is of US having a standard constellation is 31 satellites, GLONASS which is Russian is having constellation of 24 satellites, GALILEO European which is having 30 satellites.

But this is, remember it is a regional system. BEIDOU which is a Chinese, the standard constellation will have 35 satellites, IRNSS again regional system, will have the 7 satellite because most of these satellites are going to be geostationary or geosynchronous. So, because this is not a global one if you want to cover or provide the signals for the entire global community then you have to have more number of satellites.

So, India has decided to focus only for the regional system. QZSS which is Japan one, only three satellites because Japan being a small country and they thought that for them it is more than sufficient. Of course, the signals from other navigation systems like GPS or GLONASS or BEIDOU are also available. So, position estimation using these three global systems plus one regional systems plus SBAS, one can get a very good positioning. GAGAN as I mentioned which is Indian system, it was developed when we did not have this IRNSS or BEIDOU signals and other things.

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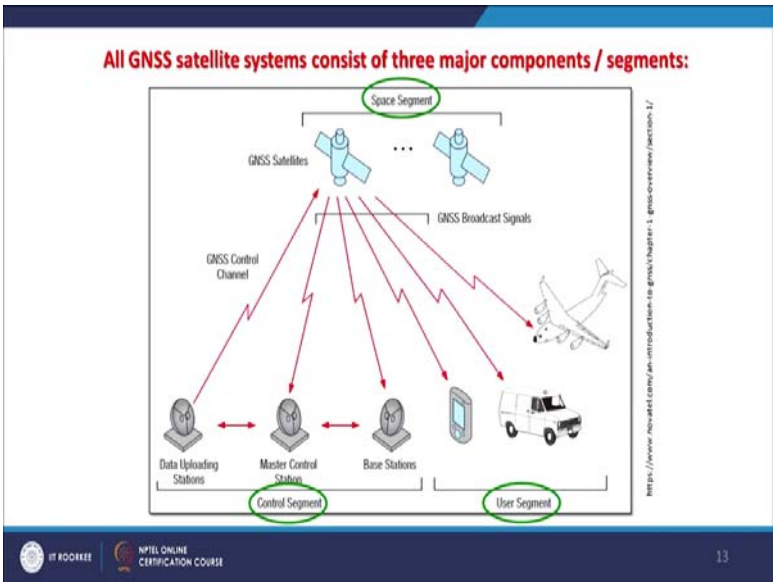

So, GAGAN was basically to augment the GPS signals and which was based on the ground for improving navigations all along the coastal lines. So, that was also there. Now all these satellite system consists basically three components, one is of course space component and then another one is this your control component or control segment and then user segment. So, these like GPS is having 31 satellites and all these are in different orbits at a very 20200 kilometer deep in space.

So, these entire network or constellation of the satellites, we put them as a space segment because they are in space. Now as also mentioned that in order to maintain the integrity of these satellites, the monitoring has to be done regularly and if there are some problems, then either a satellite has to be replaced or if repair required or correction in the orbits are required that can be done through the ground. As you can see here that you know there all the systems if we take the example here say for GPS, then there is a master control station which controls everything, then there are base stations and there are many monitoring stations all spread all over the world being a global positioning system.

And then last segment where we fall basically, which is user segment. So, we might be using a handheld device, handheld receiver or may be using nowadays a smart phone or maybe it is fitted in our vehicle car or maybe in aircrafts. All these who are using, they do not have to do or they do not have to transmit anything. They do not have to control,

manage these systems, they are just using it then that is the user segment. So, a space segment, control segment and user segment; three components or three segments of a GNSS system.

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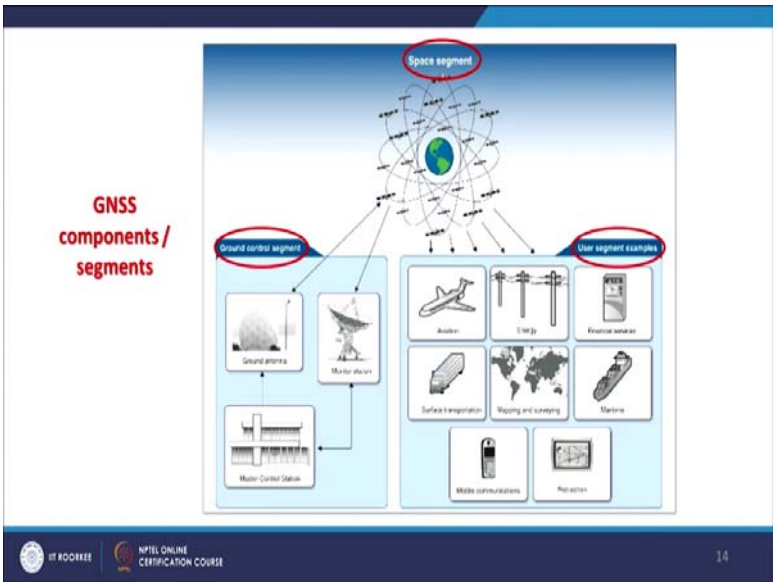

Each GNSS system will have in the similar way. Now as I said that the space segment which is purely satellites orbiting in different this is the example from a GPS then ground stations are there. Some are monitoring station, some are controlling stations, master station and then of course, finally you are having users.

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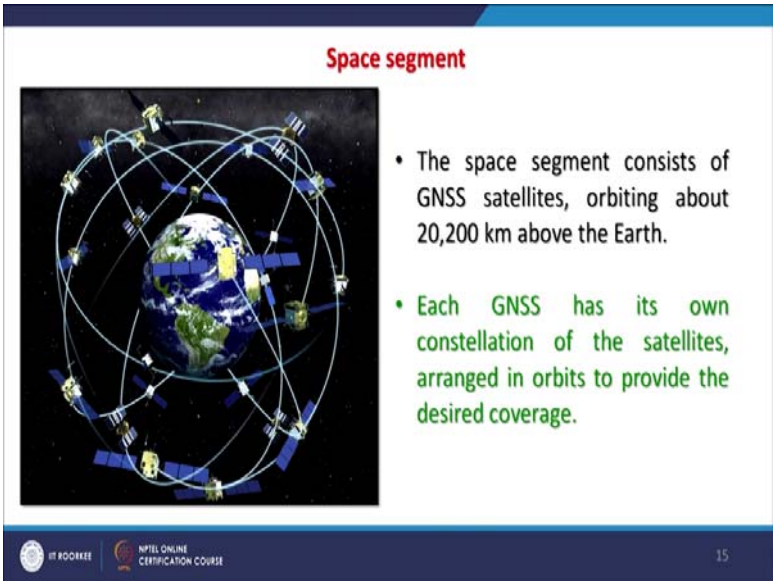

A space segment basically like we take the example of GPS 20200 kilometer all these satellites are orbiting in different orbits and each these navigation systems have its own constellation because the purpose are different. Some are regional, some are global. So, that is why each is having their unique constellation, arranged in orbits to provide desired coverage whether global or that one.

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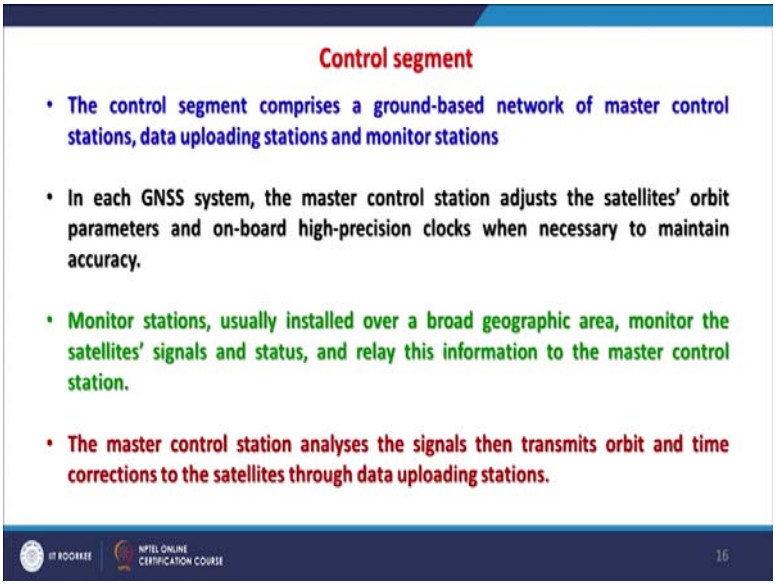

Now, control segment which comprises a ground based network of master control station, data uploading stations and monitoring station.

Data uploading because our receivers are just receivers, they cannot upload and why uploading because if corrections are required in the satellite orbits or other things or maybe corrections in the clock or some other then there has to be one master control station, from where they can upload the data to the satellites. And monitoring stations are spread all over the world for global systems. In each GNSS system, you will have a master control and then which adjust the satellite parameters, basically the orbit drifting and onboard high precision clocks, necessary to maintain the accuracy and monitor stations usually installed over a broad geographic area, may be in different parts of the world.

Monitoring satellite signals, status, strength, quality and then transmitting that information to the master control station for any correction if it is required. So, this is how this control segment works and user segments where we are, which basically

consists of receiver, which receives the signals, process the data and estimate the position.

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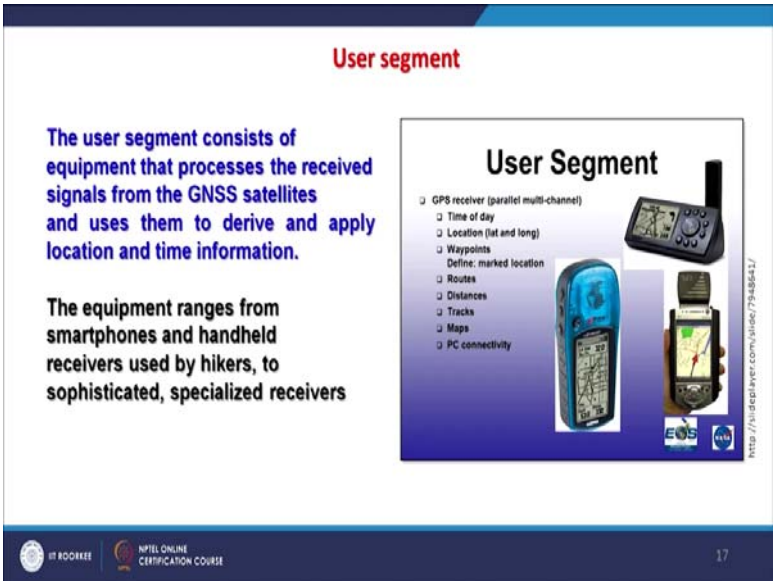

So, this is there and user segment basically will have a receiver, receiving system and these are being used now by various people for various purposes and for leisure, for travelling, for navigation and for disasters and in case of disasters and other things, all these devices are being used.

Ok. So, now, very briefly I will go through the history of satellite navigation. As some part we have already talk, but that was like dead reckoning and others, but basically this current satellite navigation history which we look then basically…

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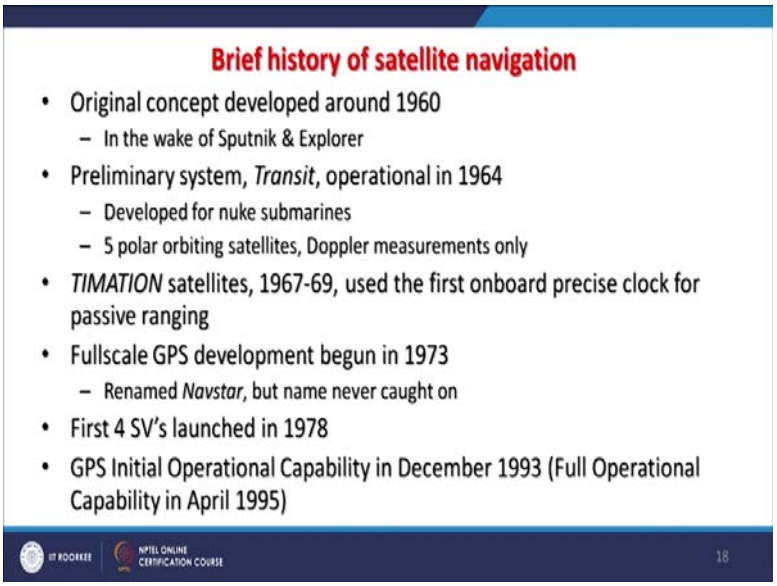

..Started somewhere in 1960 and when these satellites started being launched sputnik and explorer where launched and Preliminary systems, Transit the name of that system was, it will became operational in 1964. Basically develop for nuclear submarines and then polar orbiting satellites, which exploit this basically measuring Doppler and they were all focusing initially for in war or those army military related things.

But later on they became available to normal users or in civilian domain. TIMATION satellites 1967-69 used first onboard precise clock for passing ranging. So, this is not in one day this satellite navigation technology has developed. As you can see that since 1960 things started developing and even 67-69, these atomic clocks were started going on the satellites and people developed experience and now current navigation systems are.

Full scale GPS development begun basically in 1973 with this NAVSTAR and then it continues and not only in US but many other countries as we have mentioned are there. Initially first satellite vehicles SV is stands for. So, first four vehicles were launched in 1978 and then the full operational capability were developed in April 1995 when the constellation had complete, constellation had 31 satellites in case of GPS.

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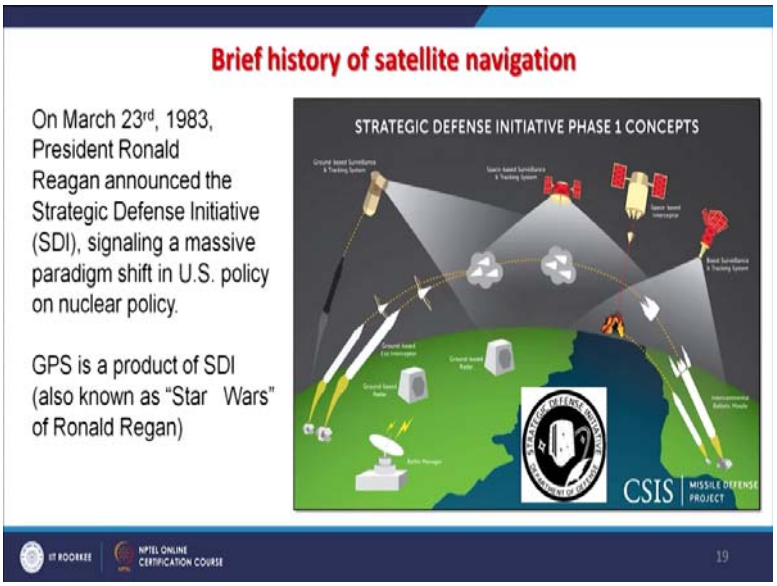

Now as mentioned that GPS was a part of a strategic defense initiative or people also called as a star war which was between these two, then enemy countries US and Soviet former Soviet Union and basically they wanted to hit each other targets with high precision and for that all this started developing. Now when initially the GPS came in the civilian domain, there use to be a problem about the selective availability; that means, that the signals we are encrypted. So, that civilians do not get a higher accuracy whereas, US army people with their receiver used to get accuracy.

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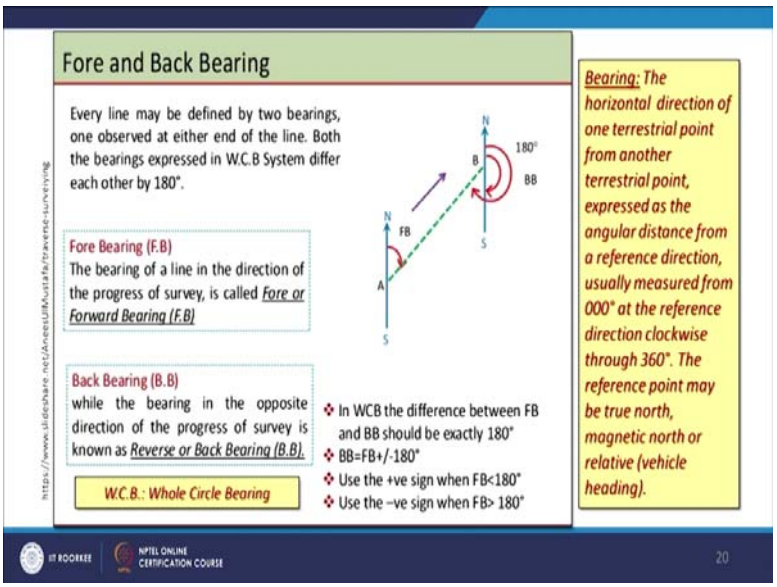

But later on that has also changed. So, as mentioned that the current GPS is a product of SDI or a star wars which was a dream project of then president of US, Ronald Regan. Now if you are having background of civil engineering or earth sciences or geology, you would know that how position is determined by these navigation systems. Basically this concept comes from this back bearing concept of fore or back bearing concept where we use to have a compass and objects which we are seeing on the ground and same time, we used to identify these objects on our toposheets as well.

So, when you take a bearing from compass of object which you are seeing on the ground, then you draw this bearing line and then take the bearing from another object and draw again bearing or this line. And with these two lines, where they will cut the back bearing. Basically why back looking because we are looking towards the object and writing down the other direction that is the direction towards us that is why it is called back bearing.

So, if two back bearings at or two objects back bearings are plotted on a map, then where they will cut probably that is the position where I am standing. Now how to make sure that I am more accurate in my position estimation, then take the back bearing from third object. And if the line again cuts on the same first crossing of these two back bearings, the third one also cuts at that place then I am sure that I am having more confidence about my position estimation.

So, almost this concept, but instead of in 2D, it has been implemented in the 3D with these navigation systems. So, what the satellites are doing basically, that they are transmitting their position as well as the other data like timing and other things and when it is received on the earth by receiver, then the time taken is calculated and multiply by the speed of light and this is how you get the distance of the satellite. And if you get like in back bearing concept, if you get a bearing from two far apart objects, then you can get the first position estimation.

Similarly, in case of these Satellite Based Navigation Systems, because you say we are talking not in 2D, but in 3D. So, instead of bearing from two or range from two, here you require at least ranges from three satellites and then in order to get the z position also, you require range from the fourth satellites. So, they will be basically cutting or each range will basically constructed imaginary sphere, you can think if you wish and when

these four spheres will cut, then you are sure that this is my position on the surface of the earth.

So, this concept basically was there and in the form of back bearing concept that was in 2D, in case of satellite based navigation system this as now in 3D.

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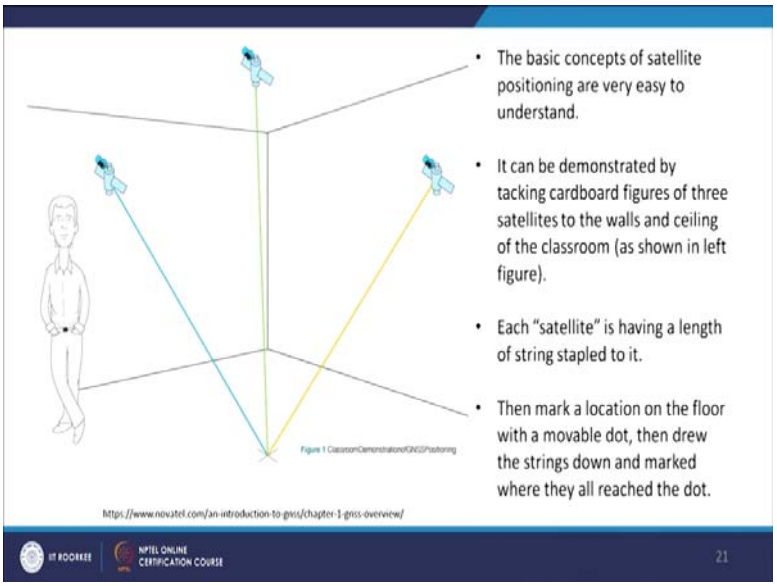

As in this figure, it is shown here that a signals from three different satellites are coming and since their ranges are cutting at one location so, I as far as my horizontal position is concerned, I am sure that I am standing here. Then there might be some accuracy issues are there, which depends on the signal quality and other things, but if I am getting signals from 20 or 12 satellites simultaneously of different navigation systems or even one navigation system, then my position estimations is going to be very accurate.

Because all these ranges which we are seeing here is a schematic, if they are cutting at one location then of course my position estimation is going to be much better. So, the basic concepts of satellite positioning are very easy to understand as I have just explained, it can be demonstrated by taking, you know cardboard figures of three satellites to the walls and ceiling of the any room and there, when you draw or pull a thread from there, then you can have this kind of scenario.

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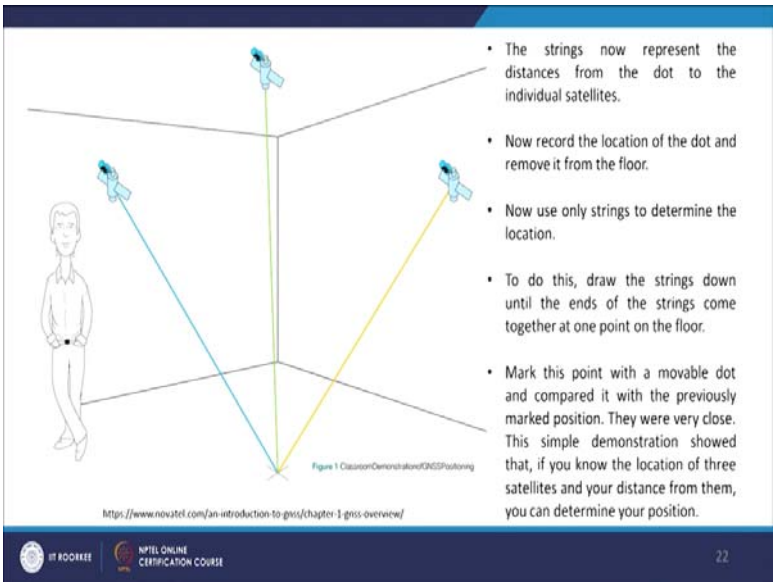

Same way, the satellites also do instead of some strings, you are having signals and ranges are there. So, this is how the position estimations are done by the satellite. We will be also going through in much more detail about these how the positions are estimated.

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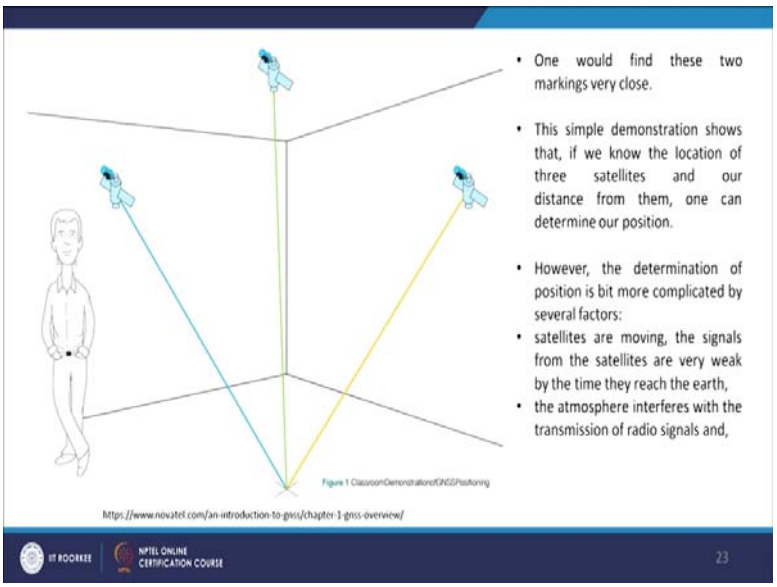

And that thing, but basically, more the satellites signals are available to the receiver better the position is going to be. And that is why it is mentioned that if you are looking

for good accurate position, it is always suggested that one should go in open area if it is possible to get better position.

And there are of course, some factors will play if you are in a valley, in a mountainous area, then your open sky is very limited. You may have a poor signals therefore, poor position estimation. Or sometimes a little bit, though it is a all whether condition systems, but still if there are very harsh weather is there, sometimes atmospheres can also bring some distortions in position and because after all data is coming through radio signals that may get disturb. So, the position may also get changes.

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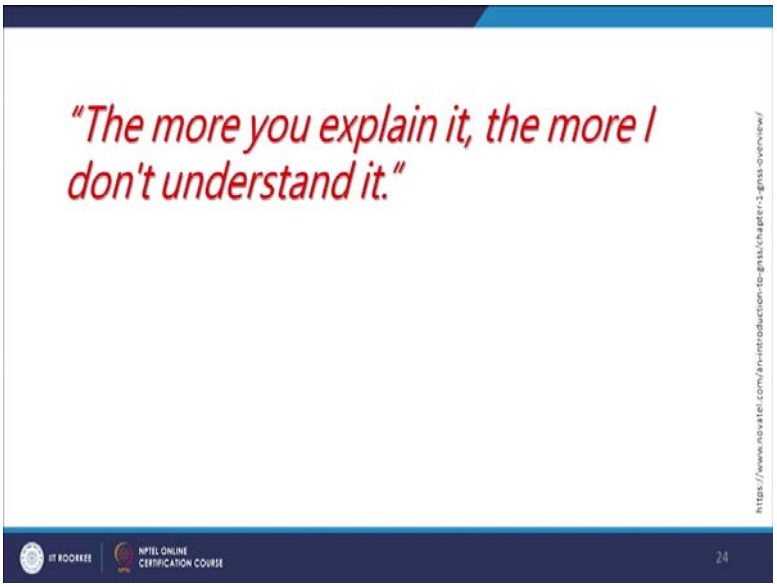

So, the more basically in this navigation system as you have seen the brief history and whatever is happening today or currently or in future that it can be said that more you explain it, the more I do not understand because things are really getting more sophisticated or sometimes you can call as more complicated, but on the other side they are getting more accurate, more quicker and wide applications; lot of applications of these in navigation systems are coming. So, at this point I stop here.

Thank you very much.