Control Engineering
Dr. Viswanath Talasila
Department of Telecommunication Engineering
Ramaiah Institute of Technology, Bengaluru

Module – 11
Lecture – 01
Navigation – stories and some basics

Hi my name is Viswanath Talasila. I am an associate professor at Ramaiah Institute of Technology. And I am offered this course together with Professor Ramakrishna Pasumarthy of IIT Madras. We are going to now module to 11 the first lecture of this. We are going to be looking at some applications. Applications of some of the some of the theory which we have learnt in the previous lectures and the specific application which we are going to focus on is a navigation.

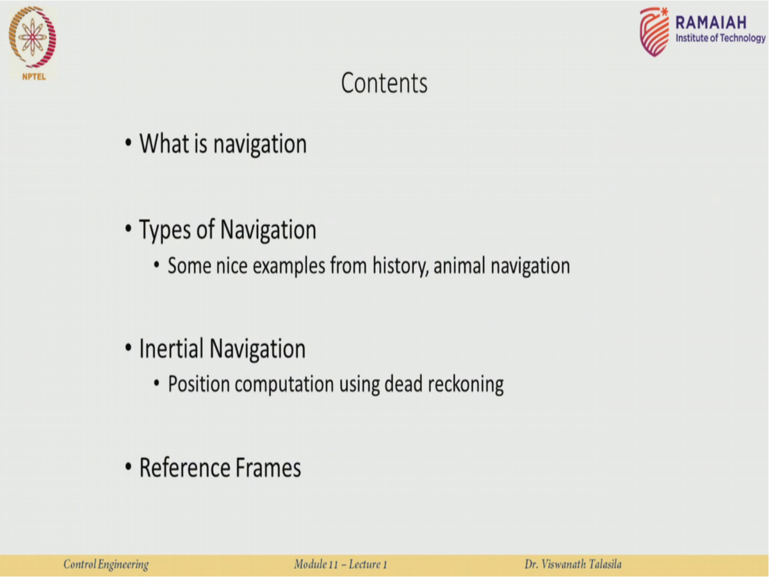
To be more specific we are going to be looking at the notions of how transfer functions filter design, you must have sorted in bode plots and those kind of things low pass and the high pass filter. So, we are going to be looking at how they are relevant in the context of navigation. We could take a lot of different applications there is a specific reason why I have taken navigation, and it is as follows. So, in most control courses we see that the traditional application areas are for electric circuits like power systems or mechanical systems which are robotics and so on. But navigation is another very big application area, and there is quite a lot of interest in control systems also modelling which is very relevant and required in navigation. It is important for all students to remember that when you talk of control systems, controllers does not exist independent of a model right. So, which is why any control scores the first one or 2 unit is will be predominantly about the model of the system, only then we go for analysing say how to design controllers and so on.

In fact, the first 3 unit is will always be about modelling and analysis of systems. So, we will look today at how we can model the problem of navigation. And we will see how to bring in 2 specific concepts of control system which is the filter design and of course, modelling. The re another reason why navigation is very important is many young engineers when they go to industry or higher research. So, when looking at autonomous vehicles. You are looking at say the flight control of an airplane or a missile. The story of navigation becomes very important. And some of you would have already heard of these filters called the kalman filters may be if you are lucky you all have even heard of particle filters and so on. So, these filters are a very standard and they rate very important in the field of navigation, specifically the kalman filter is a classical feedback control design written in a in a slightly probabilistic or stochastic manner. So, while kalman filter is one of the standard techniques we use for navigation what I will be presenting in the series of lectures along with some experimental demonstrations is a complementary filter. And a complementary filter is a very simple filter it is a combination of low pass and a and a high pass filter. And we take the signals coming out of these 2 filters and we fuse them in order to get more meaningful answer to our navigation problem right.

But the kalman filter does is something far more complex. And it turns out for lot of applications we do not really need the kalman filter which is a feedback control design. It is enough to do just you can think of this as pre filtering we can just filter our signals and still get very meaningful answers to our navigation problem. So, this is a combination of modelling and control. So, let us go ahead and if you look at the slide over here you will see that I have used these words stories. And the reason for this is ash it is always nice to know how certain fields have evolved right. So, be it control system be signal processing or whatever. And navigation is actually very fascinating topic. So, the story of navigation is as old as a story of mankind or even animals and all species. And we will see with a few stories how navigation has been accomplished over the past say thousands of years. And we will see that the basic concepts of navigation have remained very similar over the last 5000 years. But change of course, is a technology for example; GPS was not there more than few decades back right.

So, technologies have changed, but we will see that the story of navigation the basic concepts have remained very similar ok.

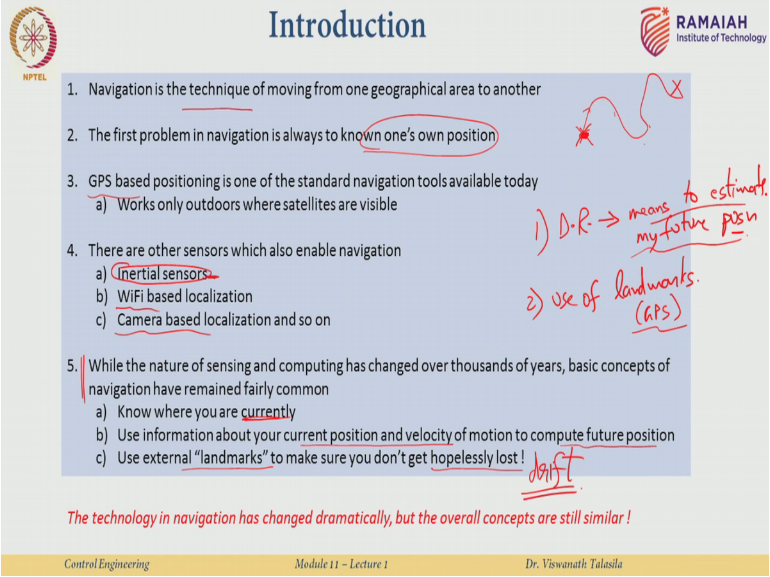
(Refer Slide Time: 05:23)



So, first let us start with some stories and the content is so, first we will see what is navigation, we will see various types of navigation. So, we look at some things some nice stories from history which includes some sad stories as well. How animals navigate, then we will look at one specific aspect of navigation in a little bit of detail called dead reckoning. We all have actually studied dead reckoning slightly before in the concept of trigonometry, we will see that we will conclude this lecture with studying reference frames. So, the basic idea of a reference frame is when I describe the motion of an object it is with respect to my own reference frame.

So, if I see for example, this duster moving from this point to this point, this motion is with respect to my reference frame. So, the really bad way of explaining this is for me this is a motion from right, to left whereas, for you this would be a motion from left to right. That is a very simplistic way of explaining, but if you remember that we all live in a 3D world. So, we describe every point in space with a XYZ say coordinate system, and my coordinate system will not be the same as your coordinate system right. And it is very important when we do navigation to be very clear about which reference frames we are going to use.

(Refer Slide Time: 06:52)



So, we will conclude with the notion of reference frames. So, what is navigation? Well, there is many definitions and all definitions are equally true the basic idea is that it is a technique or the art of moving from one geographical area to another right. So, you can move from Chennai to Bangalore you could move from say place x to place y and so on. Now when you want to navigate or move from place x to place y, the first and most important notion in navigation is to know ones own position right. Say you want to move from this point to this point right. Through whichever route you want to take whichever trajectory you want to take, you have to know where you are otherwise it is literally impossible to know where you are actually going to land up right. So, we will see some examples of calculation our own position and using our known position we will see how we calculate the path to a certain object. Then we will look at we will look at very briefly may be in just one slide or So, other navigation sensors very advance navigations sensors some of which are based on GPS, some of which are based on Wi-Fi localization and camera based localization. So, localization basically means knowing where I am locating my position.

So, we will do this very briefly just to give you an indication of how advanced field of navigation has become. Our primary focus will be on inertial sensors, we will see that a little bit later. So, point number 5 is really crucial and it basically says while the nature of sensing GPS sensors cameras Wi-Fi's and so on while they have changed even computing has changed over thousands of years, 3 basic compote of navigation have always remained and still being used in exactly the same way. The first is know where your current position is, we already talked about that. The second is using information about your current position and velocity we will see that velocity is not the only requirement, but for now let us assume velocity.

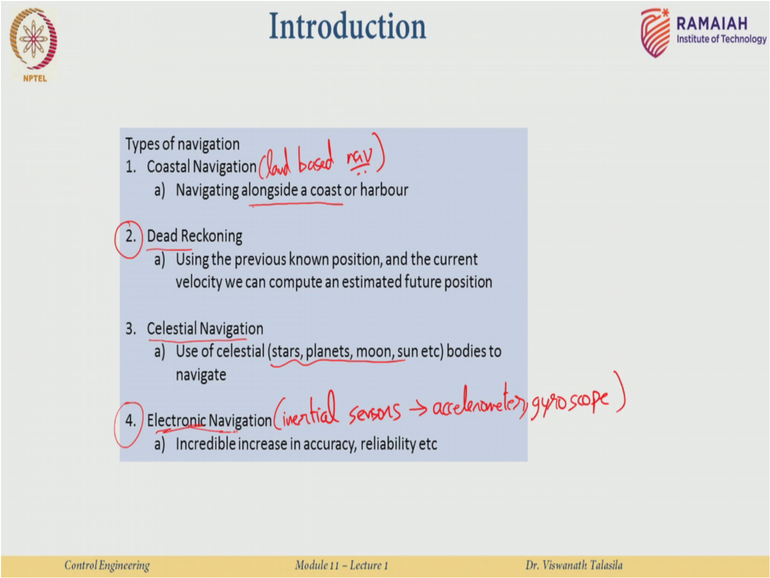
So, using the information about a current position and velocity you can actually compute what will be your future position. And finally, you always will make use of external landmarks to make sure that you actually do not get into I mean what I call hopelessly lost this is actually technical problem called drift. Before we go ahead let me give a small indication of how we normally navigate if I need to go if I need to move from this position where I am sitting right now to if I need to leave this particular room I have a fair estimate of the map of this area right. So, I know where the walls are I know where the chairs are I have a rough estimate of the distance which it takes for me to go from this point to exiting the door.

If I close my eyes and I start walking, and all of you should really try this experiment at home, if I close my eyes and start walking we have a reasonable idea as long as you do not fall down we have a reasonable idea of how much distance we are covering right. For example, if I close my eyes and walk from this point to the end of the room I would not say that I walk one kilometre, I would not say I walk one meter. I will be in the range of may be 5 meters 10 meters or something. So, I have a fair idea of how much distance I have covered in which direction I have gone alright. So, that is a little bit the problem of navigation. If I open my eyes now I can see external landmarks, I can see there are chairs over here I can see these gaps in the corridor all these additional. So, called landmarks they help me to navigate far better.

So, in navigation we always at least the advance navigation we always use 2 kinds of techniques. So, the first one would be called it is actually called dead reckoning, and it basically is a means to estimate my future position based on my current information. And the second thing is the use of external landmarks. And for those of you who read this subject in a little bit more advanced way you will see that GPS is actually one of these beautiful concepts where we use external landmarks which are satellites and space to actually help us to localise where we are, and these inertials sensors are the ones which are going to be used to estimate my future positions and so on ok.

So, the concluding point of this slide is the last line in read that the technology for navigation has changed dramatically, but the overall concepts are still very similar alright

(Refer Slide Time: 12:07)

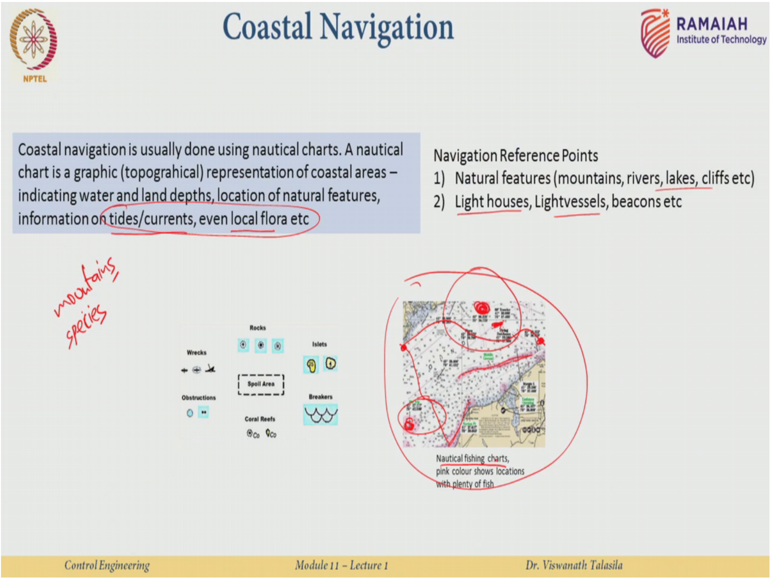


So, what are the various types of navigation? Obviously, we had say coastal navigation you could also include land base navigation right. In the ancient days so, people would move from say from Calicut all the way to Indonesia. So, that is entirely the coastal navigation the sea routes. Then people may have wanted to move from, let us say 2 different kingdoms in ancient India and there will be the land base navigation. We will be focusing more on a little bit on coastal navigation in our in our lecture. So, coastal navigation basically is navigating alongside a coast.

Alongside a coast means you usually are able to visually observe or see the coast, and we will see why that very important. And the second type of navigation is dead reckoning; we will go into lot of detail about that. The third type of navigation is celestial navigation where we use stars planets moon so on, to actually help us to navigate and we will again go into a little bit of example to see this. We will look at the concept of dead reckoning with electronic navigation in a lot of in a lot of detail, by specifically using what are called inertial sensors. And inertials sensors many of you are aware of at least one of them, the famous accelerometer which you get in your phone when you rotate the phone from portrait mode to landscape mode right, the screen also rotates.

And we are also going to look at another sensor called the gyroscope. So, first we look at coastal navigation we look a little bit at dead reckoning, how humans do it, how animals do it and then we look at celestial navigation. And finally, the rest of the whole lecture series will be on electronic navigation for dead reckoning.

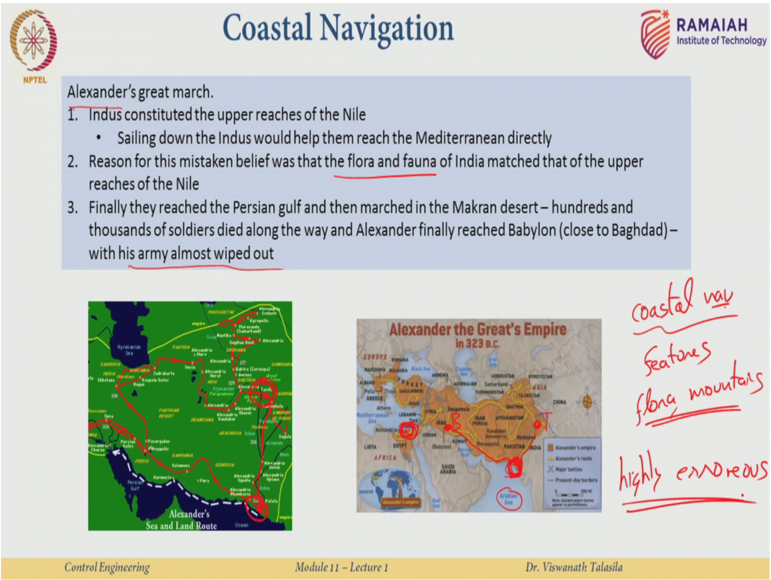
(Refer Slide Time: 14:09)



So, what is coastal navigation? It basically loosely speaking if you talk of ancient times, coastal navigation was when you when you need to move from one point on the coast to another point may be hundreds of kilometres away you would use specific natural features. So, for example, you would use may be some mountains which are along the coast. You would use certain species of animal fishes and other kind of marine species which you see along the coast, you would actually use tides and currents. So, along the coats there would be certain regions which are very strong currents and other regions which have really very mild currents right. So, we you would use all this information to be able to say that I am at this particular position. At a different position my tides would be different, the species of animals would be different, I may not have a mountain at all and so on. Or you could use light houses light vessels and all these other features.

So, if you look at this particular map over here it is called a nautical fishing chart and all the, all the pink shaded areas may be it looks like magenta all the pink shaded areas are where fishes are available in plenty. So, a person who is actually navigating along this coast say in this particular route. If the person actually is able to see that there are lots of specific types of fish in this particular area, and they will actually have a fair approximation of the location. They will know that they are somewhere within this vicinity whereas, if they come in this region and they see a different species of fish over here they will know that there could be somewhere in this viscidity. They will certainly not be here right because those species of fish do not exist over here. So, these are these are the nautical fishing charts. Like that you of course, have the nautical charts for the coast lines which depict the mountains so on and so forth. So, that is coastal navigation and this is one of the predominant ways that ancients would actually navigate along the Indian coast or other countries as well.

(Refer Slide Time: 16:46)



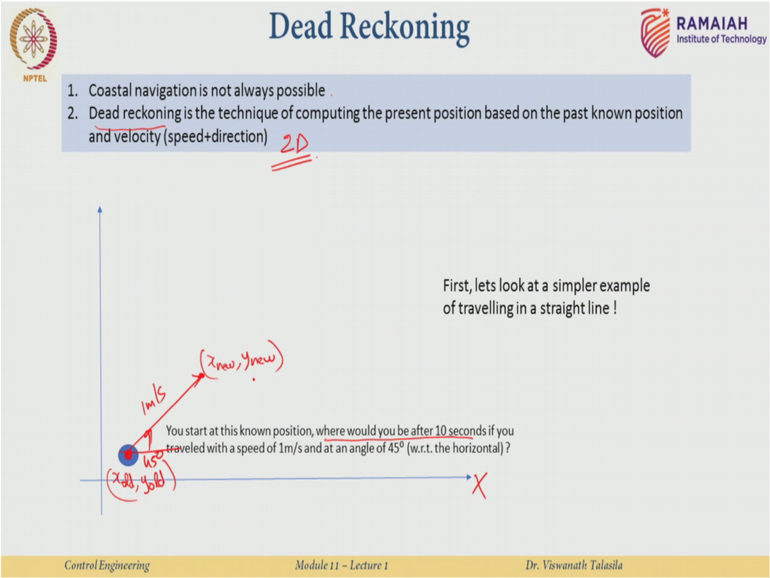
Let us see one very interesting story of coastal navigation from history. And this focuses on the Emperor Alexander's great march to India, where he fought some battles and then eventually he had to go back. And we will see what actually happened. So, there is a place called taxila over here, and Alexander after he finished his battles he wanted to march say further into India, but his generals they were actually very tired there was almost going to be a rebellion amongst the soldiers. So, they convinced Alexander that let us go home enough war is done. So, a decision was taken that from taxila they would actually have to go back to Babylon where the empire was. So, let us say taxila was somewhere over here, and Babylon which is modern day Baghdad in Iraq was somewhere over here.

And the idea was that Alexander and his army would actually navigate from taxila to Babylon or modern day Baghdad. And based on the on the surveys which his people had done they believed. So, if you look at this yellow line over here this is the it is the Indus river. So, it is much more clearly visible as these blue lines in this particular chart right. So, this is the Indus River and what they believed is if they sailed down the Indus River and they reached this coast. So, this particular coast they wrongly believed that this coast was the same as the upper reaches of the Nile, which is I would have said yes which is over here. And it is must closer to Baghdad and is much easier to get (Refer Time: 18:37) from taxila.

And the reason why they believed that this area over here was basically the upper reaches of the Nile River near Egypt was because the local flora and fauna the species of animals and other things fishes actually matched that of these 2 places. So, the kind of fishes you would get here were very similar to the fishes you would get there, the kind of trees which would grow were very similar in both cases. So, what Alexander did then they marched all the way down to this coast and what do you get you do not get the Mediterranean Sea over here right. You get the Arabian Sea when you come over here, having discovered the mistake now because this was a completely wrong coastal navigation, they now had to march all the way across the desert where thousand and lakhs may be lakhs of soldiers died before they reach Baghdad.

So, this was a great story in coastal navigation which almost ensured the Alexander's army was wiped out and actually he never recovered from that and he eventually died. And the So, the story here is that coastal navigation which is built on using certain features like say flora the mountains along the coast and so on and so forth, can be highly erroneous. And we will see that this is a typical feature of most navigation techniques right. So, that is about coastal navigation.

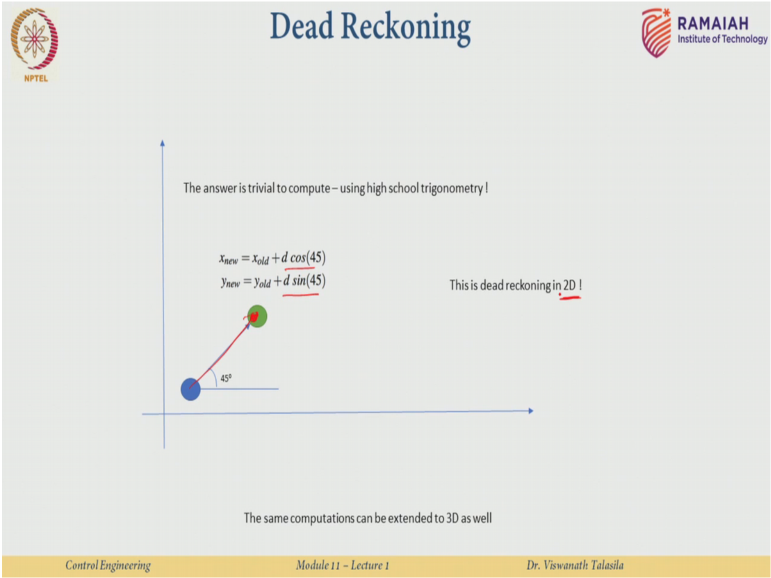
(Refer Slide Time: 20:27)



Well next move to dead reckoning dead. Reckoning is a very simple and very easy to understand. So, of course, coastal navigation is not always you may not be at the coast or you may not have interesting landmarks to observe, even on land and then navigation becomes a little bit tricky. That is why we use the concept of dead reckoning, which is the technique of computing your current position based on your past known position and the speed and direction in which you have gone. And the problem into 2D, let us look at the problem in 2D it is scales to 3D in a very similar way.

The problem in 2D basically says the following if you start at this particular location and you moved 45 degrees, 45 degrees with respect to something, but let us say in this case it is respect to the x axis. If you start at this position and move 45 degrees with respect to the x axis, and you move at a speed of say one meter per second, alright in this direction. Where would you be after 10 seconds? Where would you be after 10 seconds? And this is very easy to calculate from trigonometry right. So, if you call this initial position as x old and y old we know from trigonometry what these 2 coordinates will be right. I encourage you to retry this before you move on to the next slide.

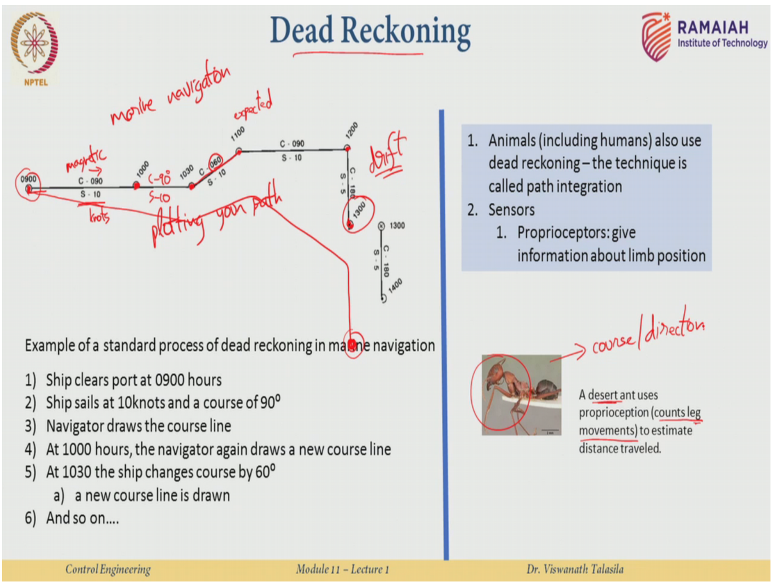
(Refer Slide Time: 21:59)



And it basically follows from the basic trigonometric relations of this one.

Where d is basically is the distance which is travelled. So, this is basically dead reckoning in 2D. Note that we are not talking about accelerations velocities and other kind of thing measured by sensors, we actually know at what speed we are travelling at like how the ancients would do, have an estimate of the velocity you are travelling at and based on that you actually calculate your current position. Although this is done in 2D exactly the same concept extends to 3D as well ok.

(Refer Slide Time: 22:36)



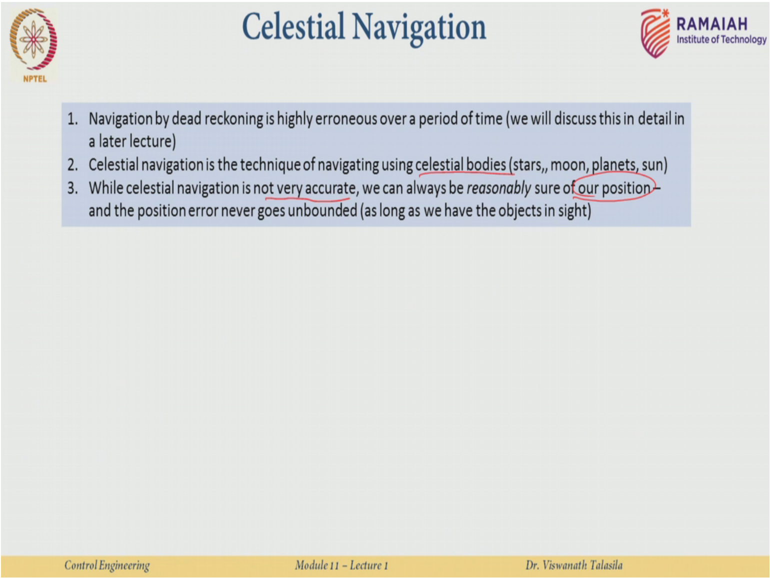
So, that is dead reckoning. Now just a small example of how we would do dead reckoning in the ocean. So, this is in marine navigation, these charts which is shown over here is basically one way of computing or plotting. So, I would actually say plotting your course or plotting your path right. So, they normally use a word course in navigation. And the basic story here it goes as follows. Your ship has started at 9 a m in the morning, and it is moving at a speed of 10 knots, knots is a is a marine way of computing speed. So, it has a certain relation to meters per second or kilometres per hour.

So, your ship is moving at 10 knots at an angle of 90 degrees at a heading of 90 degrees and this is a magnetic heading. So, with respect to your compass which looks at magnetic north you are moving at an angle of 90 degrees with respect to magnetic north. Then what the navigator does is to plot? What would be the expected position of the ship alright at 10 a m? And in this particular example what has happened is at 10 a m the ship captain decided to maintain the same speed and to move at the same what course of 90 degrees with respect to navigation. And then the navigator waited till 10:30, when the captain decided to make a change in the path or the course of the ship to 60 degrees moving in the same speed. Then what the navigator does is to plot what is the expected position at 11 o clock. So, apart from the first one all these are expected positions, where you expect your ship to be. In the same way they would plot all the positions.

Now we will see in the next lecture that if this is the computing position based entirely on dead reckoning the actual position, now I am drawing this roughly this would not be the real case it may be far worse than what I am drawing. The actual position may actually be something like this. And this would be the actual position where the ship actually land up. And the reason for this massive difference in the estimated position versus the actual position is because of the condition called drift, which we will go through in a while ok.

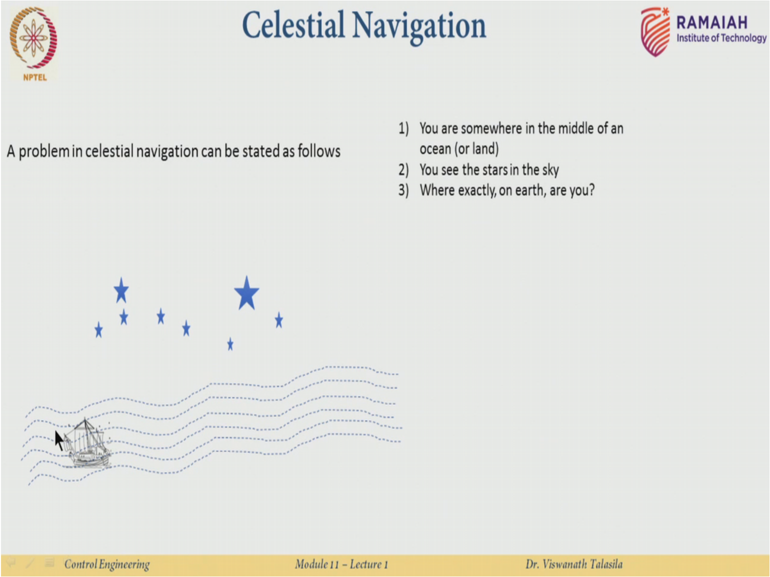
So, that is how you do marine navigation dead reckoning, you are not using any coastal landmarks or any such thing just only dead reckoning. How do animals do it or even humans? So, if you look at this particular desert ant it is Saharan dessert ant and it uses a technique called proprioception it is a biological term which basically means that I have an idea of how much I am actually moving. It is a technique of proprioception and it is able to count it is leg movements to estimate the distance travelled. So, it is able to count the leg movements right. To know how much distance it has travelled, notice that we still are not talking about how this guy gets the course or the direction of movement, I will I will come to that in the next slide. So, animals humans all species they actually have a means of estimating how much they have actually travelled, that is a basic notion here and it is based on dead reckoning.

(Refer Slide Time: 26:27)



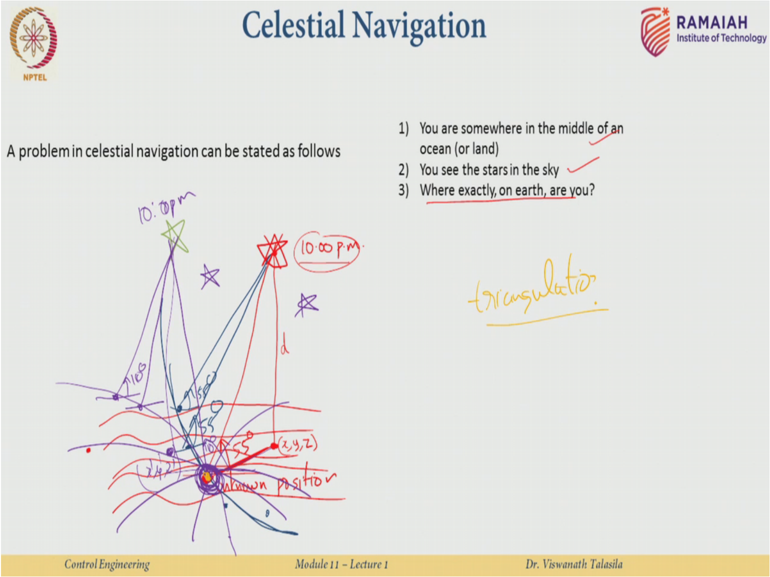
So, let us look at celestial navigation and we will see how these ants are actually able to navigate accurately with celestial navigation. So, celestial navigation is a the art of navigation by using celestial bodies, starts moon and is really how it was done in the ancient days. The cool thing about celestial navigation is that while it is not very accurate. You can always be sure reasonably be sure about your position. And we will see why that is so. So, you will never be completely off. So, you will never have errors the way that you had in your dead reckoning, which leads you to really I mean completely erroneous position then when you really are.

(Refer Slide Time: 27:17)



Celestial navigation avoids that problem. In fact, we will see one example of this shortly. And the example is something like this. So, let us say you are in a ship in the middle of a ocean. And this is your current position. You do not what a current position is by the way. So, I am telling you are over here, but you are the ship captain and do not know where you are. All you can see assume it is night time; all you can see are the stars in the sky. So, you are somewhere in the middle of an ocean all you can see are the stars in the sky the question is where exactly on earth are you. So, how you, how would you solve this problem? So, the way it was done was actually this. So, let us say you are at this unknown position in the middle of ocean or somewhere.

(Refer Slide Time: 28:03)



And you see a star over here. I do not know, how to draw a star I am imaging it is something like this. So, you see a star over there right. So, this is all your beautiful ocean over here it is a moonlit night may be you are listening to some nice lata mangeshkar songs, but you have absolutely no idea where you are.

Now, how would you actually compute your position? So, to be more precise, let us say you have seen this star at 10 p m at night. Now you have a book I believe it is called a star map and the location on earth based on where the stars are. It basically says if you are able to see this particular star at 10 o clock, then if the star is perfectly above your head. So, if I draw perpendicular line from the star and it falls on earth over here. If the star is perfectly above your head at 10 p m you know this location more specifically you know the coordinates of the location. It is usually given in latitude longitude altitude, but we will skip that for now. So, you know the actual location where you are if the star where perfectly above your head. The star is not above your head, you are somewhere over here right. And you are seeing the star from this position. Now let us say that you have a means of measuring the angle at which you are able to observe the star from here let us say it is some 55 degrees. I am standing here I am seeing the star is 55 degrees with respect to me. I have this fancy book which says that at 10 o clock if I were here I would see the star exactly above my head.

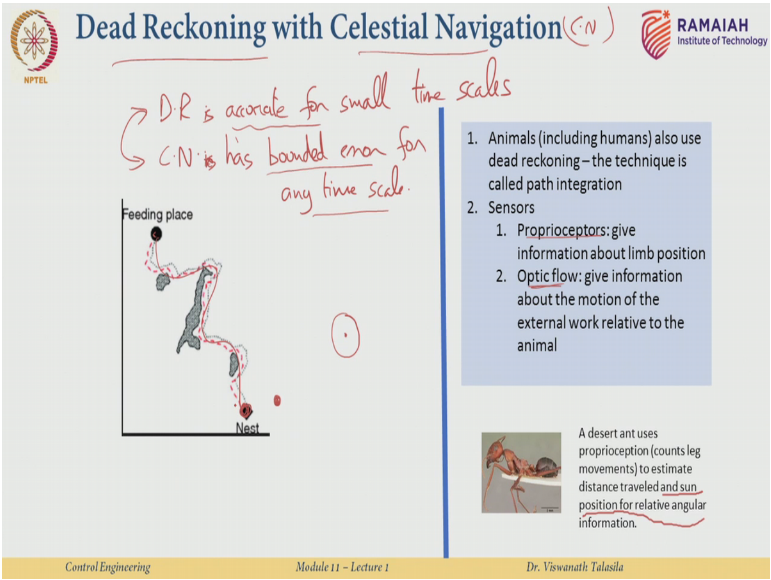
Now it turns out with very simple trigonometry you can actually compute what is the distance from your unknown position to the actual position if you if the star were exactly above your head. This is a very simple trigonometry, and it basically assumes that you know the distance from your position to the star. And the ancients had really interesting methods of calculating this star again based on standard trigonometry.

So, if you know this distance alright, and you can calculate this you can assume that you are somewhere over here; however, life is not that simple because what would actually happen is all it is saying is that with respect to XYZ with I have drawn over here, I can be anywhere at a particular angle of 55 degrees right. You can be here you can also be here 55 degrees and so on. I can be anywhere on a circle right. And you do not know exactly where you are. So, actually it is a complete circle I can not draw it here because it looks weird. But otherwise it is a complete circle and anywhere on this circle you will see this particular star at 55 degrees. So, you know approximately where you are on a circle, but you still need to know where exactly you are. And the way they would do that is to use another star. So, you would see another star and see I can now draw stars properly, you would use another star and you would again do exactly the same. So, you are in this unknown position I have a certain angle reference to that position and it says that may be I am at some angle at one 110 degrees or something like that right. I really do not know exactly, but say some one 110 degrees. And let us say you have seen this other star again at 10 p m at the same time as you have seen this star.

We again know from this from the star map chart of us, that if the star were visible at 10 p m you would have to be somewhere over here. At this new x prime y prime z prime. So, I now know 2 specific positions if the star were above my head XYZ or there is x prime y prime z prime. You saw with XYZ I am able to calculate this distance, and I know that I am somewhere on this great arc on the great circle. With this new position I can again do the same, and what I would get is a different arc. So, maybe it is something like this, which means that anywhere on this circle I will see this star at that one 110 degrees whatever you have mentioned right. Anywhere on this circle. Now we see that these 2 these 2 circles are intersecting at this position right. And that is your actual position. For those of you who are little bit curious you may have either guessed by now or you may want to know that you still cannot get an exact position fix by doing this because this area over here is really large with twos with 2 circles you take the intersection of these 2 circles you will actually get a very large area. And you could be anywhere in this area and get exactly the same information.

So, the even better way to do it is now look at more stars in the sky. 3 stars, 4 stars, 5 stars then I get all these circles and the intersection of these circles will become a much smaller region right. And that much smaller region will actually be where you really are. So, this is how you would do celestial navigation. It is basically the problem of triangulation, nothing more that. And triangulation we see is a technique that is that is being I mean followed even in these days. So, right so that is we have done dead reckoning we have just done celestial navigation.

(Refer Slide Time: 34:17)



Now, let us see what happens when we combine dead reckoning with celestial navigation. Know that celestial navigation it is not always easy to get an exact say distance measurement. Because as we have seen in the previous slide we get a fairly reasonably accurate position of where we are, but the position is not accurate within few meters something like that like. You would say that if I am able to see the star from this position and after doing all these calculations which we have done over here, you would say I am approximately in this area. And the could be as large as a few meters. And why that is not good? It is not good if you are an ant or an animal which is searching for food right. And then it needs to come back to it is house.

So, let us say there is this ant over here and by the way this is also true of autonomous vehicle navigation. So, you are over here you do all this [FL], you are looking all over the place and you find some food over here. Now when you come back you need to know exactly where you need to come back. If your position calculation is erroneous even by a few meters, the ant instead of going to this nest may land up over here, where I do not know there may be some predator which eats ants. I am not sure. So, it is not really a very advisable thing to use only celestial navigation. We know that dead reckoning is very inaccurate. When you combine dead reckoning with celestial navigation we actually get a far more accurate picture. And the idea is very simple. Dead reckoning is accurate for small time scales, specifically this means if I am navigating for a very short amount of time like say a minute or 2 dead reckoning is very accurate. Celestial navigation is celestial navigation has bounded errors for any time scale. So, even if I navigate for one hour 10 hour 100 hours 200 hours one year, I know that my error will always be bounded. We have seen that in the previous slide if I am able to see the correct stars or any such thing I will always know reasonably well where I am. It will not be perfect, but it will be reasonably well.

So, when you combine dead reckoning with celestial navigation, you can get the accuracy at the at the small time scales, and you will always make sure that you do not have unbounded error which is a common feature of dead reckoning through drift for any time scale. And In fact, the desert ants actually use these kind of things. So, what this guy does over here it uses these proprioceptors which counts the leg movements, it knows how much distance it has travelled, it uses the concept of optic flow to get the feel of a velocity. So, you take this object again. So, let us say that I move this object like this right. I have an approximate feel of the velocity of this object right. I know that it moves from here to here in about a second. The same thing if the object is static and I am moving across like I am a ant which is actually moving across this or I am robotic autonomous vehicle moving across this, I have exactly the same perception of movement. And I know how fast I am moving with respect to an object. So, that is a concept of optic flow. So, it gives velocity whereas, proprioceptor gives distance. So, now you have a lot of information with you. And then this desert ant it actually uses the position of the sun for the relative angular information right.

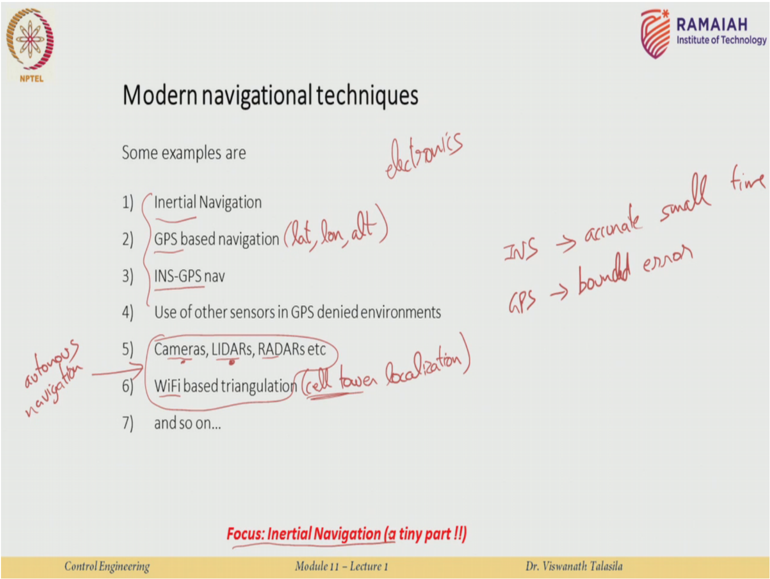
So, this is a the celestial navigation which is done. So, it combines. So, that it always knows approximately where it is it never gets really badly lost. And the dead reckoning ensures it is always accurate in the small time scales. So, the fusion of these 2 will make sure that the ant always lands up at home alright. So, that is a combination of dead reckoning and celestial navigation.

(Refer Slide Time: 38:41)

I couldn't resist putting this slide, because I think it is really fascinating and it shows how we ancient Indians actually did some amazing navigation. So, Indian navigation is around 3000 BC old or even older. They had lot of trade links with Mesopotamia which is current Iraq, and also Kuwait. It is around 2900 BC really 5000 years ago. And the world's first dock for ships lothal was built around 2400 BC. And one of the earliest navies which India had was during the Maurya time, around 300 BC the Chola empire lots of us would have heard, had it is influence extending all they across these regions and of course, you could not have done that without extraordinarily good marine time navigation.

In fact, if you look at this picture over here, this is in a museum somewhere in Calicut or some where I am really sorry, I am not able to recall that. They actually got the (Refer Time: 39:52) of a Chola era boat, and they reconstructed based on the drawings that are available from the Chola empire. How the boats would have looked back in those days and by those days I mean, around say around thousand AD. So, this is actually a boat which was from that era is so beautiful. And of course, fortunately or unfortunately as history has taught we had the visit from Vasco Da from Vasco Da Gama 1498, and things changed after that. And certainly we have not done any exciting navigation at least marine navigation beyond that. Until the last few years when the Indian navy now has started to go, to Antarctica and other really need places. So, it is a brief history of the great adventures of Indian navigation, there are some externally good books on this it is fascinating and beautiful and you should actually read this to get a feel of what navigation was in those days.

(Refer Slide Time: 40:55)



Ok so, done with history done with stories now let us move onto some other cool stuff. So, we have seen coastal navigation dead reckoning we have seen celestial navigation. Now the more modern navigation techniques are highly based on electronics right. And the one of the most classical examples which all of you would have used or really aware of is a GPS based navigation. So, this gives you your position on earth in latitude longitude and altitude. So, GPS works basically by how the receiver in your phone or your GPS receiver look is looking at satellites in space.

The other thing is inertial navigation will be discussing that lot in these lectures. And inertial navigation uses accelerometers and gyroscopes. The really accurate type of navigation on earth is by a combination of INS and GPS. So, it is basically a fusion it is called INS GPS system inertial nav GPS based system. And here again as we have talked about in the dead reckoning and celestial navigation, the inertial navigation system is very accurate over small time scales, over small time scales. And GPS has bounded error, it is not perfect as many of you would have observed if you are trying to navigate with GPS you actually get lost sometimes like couple of streets away from where you are from where you should be, but it is a bounded error.

So, if you are in Chennai it would not show Bangalore and vice versa. Whereas, if you navigate with a INS for say a few hours and you are still in Chennai it would actually show Bangalore or something else. So, these are the standard navigation sensors which are used. Recent research has focused on the use of cameras, laser based ranging sensors and radars to also do navigation, there is a also Wi-Fi based navigation you would have possibly not used Wi-Fi, but you are you would have used your cell tower based localization, when sorry you would have used your cell tower based localization when you are booking your ola or uber vehicles.

So, when actually doing the booking it shows where your current position is on the map and that is by the cell tower based localization. Wi-Fi localization is a similar approach based on Wi-Fi signals. So, for those of you who are really interested in looking at this you have you need to look at autonomous navigation and if you give any of these keywords say lidars or cameras it actually shows up a lot of really interesting literature; however, the focus of our lecture is going to be only on inertial navigation.