ROBOTICS
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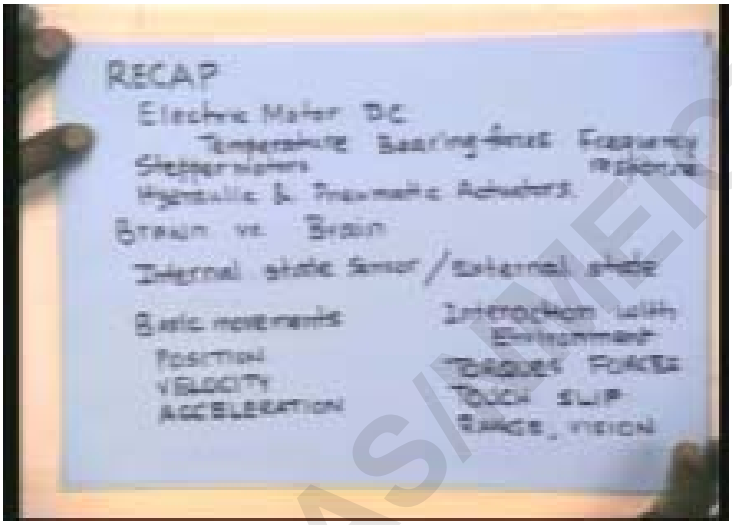
Lecturer No-9
Internal State Sensors Time(1:20 min)

Such as to recap what we being doing in the course so far in the last lecturer professor amarnath had talked to you about (Refer slide time 1:35 min)

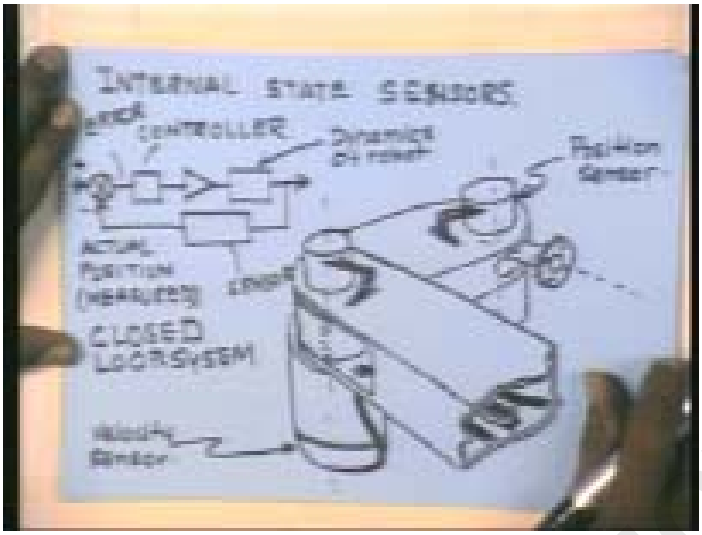


electric motors and he was particularly talking about the DC variety and permanent magnet type of motor (some noise) after introducing about the basic characteristics in last lecture he talked about important of looking at the Temperature [noise]he also talked about the importance of looking at the bearing reactions forces because these are often neglected because we are looking at the requirement of positioning and speed and the torques many times we overlook important considerations like bearing forces than also how fast you want to move things so the frequency response then he moved on to talking about stepper motors and also to some introduction to hydraulic and pneumatic activators we called at from the beginning of the course you have learned about a basically different type of applications robots are used in and the basics of robotics which means you talk about configuration of robots degrees and freedom of robots reach work space accuracy precision and then last topic that was covered was about activators so when we talk about activators we talking something that is like muscles and if you have powerful muscles if you are clumsy then it doesnt do the you cannot do the fine job so that bring us to our next topic that iam going to starts covering dealing with sensors and controllers right so its a issue of brawn which is the activators versus brain so brain is responsible for sensing and using the sensory feedback to do make the sensory activators to something going to be response the environment something which is desirable now as for as robotics is concern we have we divide the sensors in to two different types of sensors primarily they will be called internal state sensors and external state sensors okay

these are sensors we talk about we will talk about controllers after that what do you mean by internal state sensors these are sensors which help us in the basic movement of the robot so basic movements what ever assist us in doing the basic movements we cover under the internal state sensors what ever helps us in interacting with the environment Interacting with the environment with environment is basically looked as something that is external state sensors so basic movements of course are position velocity and perhaps acceleration what could be Interaction with the environment well robot has do a task which is to perhaps to do some assembly task which means there are forces which are come from the environment there are going to be movements from an environment

so torques and forces has to be able to apply it has to able to withstand sometimes we are interest in knowing something is there or not so then the issue of touch or if what we are holding in the gripper is it slipping or is it study so slip is another sensor which is important in robotics

then there are various other you can have range how for something is this primarily important for mobile robots where robots are moving around in some environment and how for if the optical is important to know then of course we talk about full fledge vision interpreting what is ahead in this scene what is around in this scene and one again if we come back to our analogy with the human beings [some noise]what are the internal state sensors to we have has any body thought about what internal state sensors you have or do you have any basically if you want to see whether we have any internal state sensors or not you can do one experiment you can close your eyes and then move your arms randomly and then keep your eyes close and ask yourself do you know where your arm is and the answer would be yes right so there is something that is apart from visual feedback apart from the fact that you may be integrating your position to see how much arm you move but you moved randomly enough for long enough time you integration will be will not be accurate because the initial condition and you know it wont deal the errors along the way but still even after a long random movement you will be able to say where your hand is what is the general orientation you will be able to feel the velocity without having look at it so there are internal state sensors and they are actually embarrassing so we do have the internal state sensors of course we have the external state sensors we are all very keenly aware of that vision you know the sense of phase touch smell all these are external state sensors which are which make as behave in a very intelligent fashion and interacted arrangement so let us begin to look at internal state sensors(Refer slide time 8:53 min)



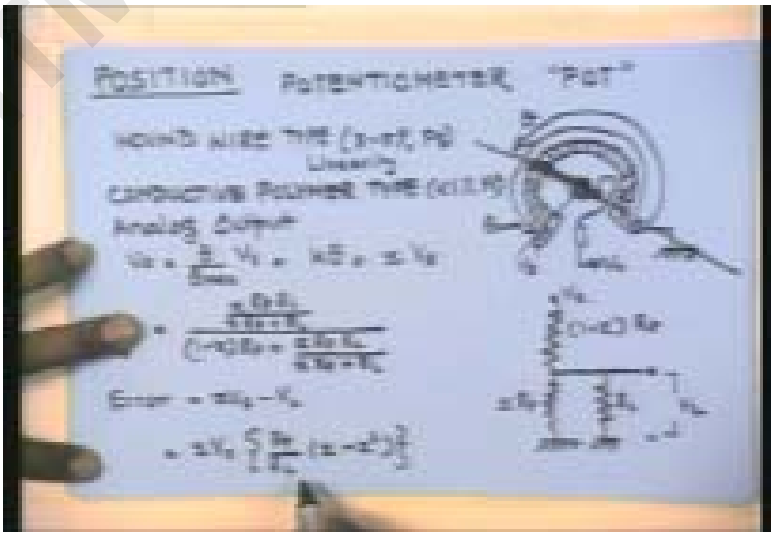
okay internal state sensors if you look at the diagram here basically drawn a typical a couple of degree of freedom of a typical robot arm what you see is one link here which is got a revolute join with respect to the link here and the new also we have the little link at the end may be the antifriction may be connected to that apparently they have degree of freedom of motion of vertical axis here vertical axis here and then perhaps the rotation about this axis here right you have different motions are here now if you are using stepper motor to drive this joints is quit possible that dont require sensing that you say that you started from your home position and then you have moved under this steps each amounting to let a point to ninety degrees then you know that move ninety degrees on the other hand if the robot is interact with the environment there is a force of gravity acting whether external force is acting then one cannot always be sure whether hundred steps actually corresponding to ninety degrees or not so in that case good to know where the robot actually is and for that you will require some kind of sensing to be done and so you will have things typically like position sensors

you may also have some kind of velocity sensor and there can be different type of positions sensors and velocity sensors obviously in real robot you will have to worry about all the signals come out from the sensors and coming through where ever you know routing of these to this controller and this actually in practical robot design this become say something you will be worry about how the cables are going to run and they will not interfere with the moment they will not get tangle they will not get damaged so those are of course of issues of practical robot design we are not going to worry about that too much basically what we are saying is that if you have if you have a controller so let as depict this controller as a block here
what the controller does is actually to look at what is desired and that depicting by error here this is desired position let say because the task typically would be we will want to take the robot one position in space to another position in space and then we want to do that we have the corresponding angles of the joins which correspond to the first state and then we need to transform them in to the second state which will be the second set of joint angles or positions now at any time you will the controller will generate something will tell the controller this is the desired position from the desired position the

actual position has to be compared and that I am showing in this flat here a plus and minus sign showing that this is the actual say position or measured position so if we take the desired position actual position and we can come out with what we called error and the controller primarily works in the error primarily it can be take other signals infant it can loop look at the desired position it can look at the next desired position to do something more intelligent but at a very very elementary level what the controller will do is we look at the desired position it will look at the actual position look at the error and then if the error is there if it is large enough then it is going to take some action which is going to be depicted as a amplifier so the error is amplified so that it can drive some kind of motor or basically the robot system

so this is representing the dynamics of robot now sensors come here because this is the actual response of the robot here we take this and measure it by using the SENSORS here and this is the signal goes as are measured signal for whatever variable we are trying to control this position this will be a position sensor if it is a velocity that you are trying to control because they are task which you will be require to control the velocity one example of that would be if you had a conveyer on which the parts are going and then you wanted to take the robot and pick up the part from a moving conveyer in that case you will have to first you have to choose a trajectory come to the part align with it then move along with it and then pick it up as its moving along so the velocity control becomes very important

so this is the kind of loop we talking about this is basically a closed loop system and closed loop system has the advantage that if there are external forces which are disturbing the motion of the robot which are always there then it can make correction and not depend on what the original command we have given for motion as in the case of the stepper motor driven robot in which you dont have a any feedback when you can say go over hundred steps but hundred steps may actually be a ninety eight steps because something obstructed it but we have knowing we dont have a sensors so sensors are very important making robot do useful and accurate motions okay let look at the some of the sensors let starts with position(slide time 16:15 min)



we look at couple of sensors which are used for sensing position the first one that you would all be familiar with what is called a potentiometer it is also referred as a POT in short this is something that you would have come across in physics laboratory for example or you would have known it any way and basically it consist of a moving arm if you are trying to measure lets say rotation of a shaft then this arm would be moved mounted on a shaft

okay and there is a resistor assume short laid out along a circular path okay iam going to draw some terminals hand of this and this moving arm is connected through a wire flexible to another terminal of the potentiometer you get the idea that if the shaft move arm will rotate the arm is expected to be in contact with the resistor that is laid out in a circular path so if you attach some power source here lets say we some supply here the ground this terminal then depending on the where this moving arm is let them color this moving arm black here so that visible

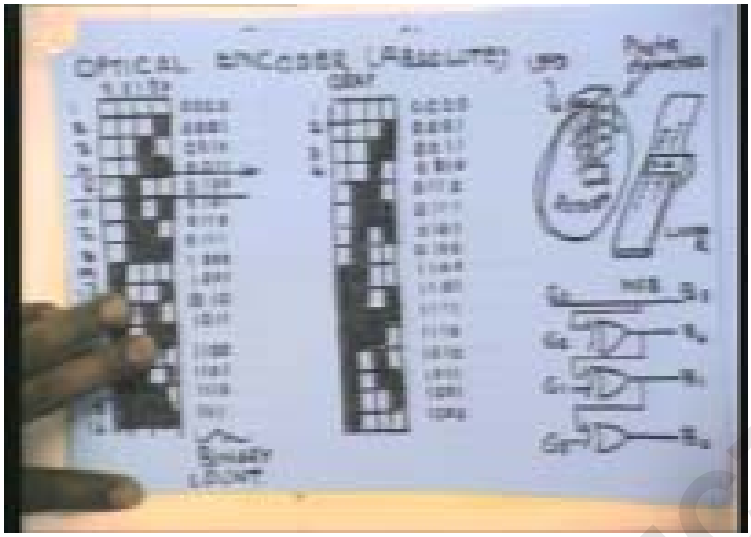
where this moving arm is with respect to the zero potential point so lets say draw one line here representing where the minimum of the you have the moving slidell contacting at the zero potential point and then you have the actual position of the so this angle here we called this theta and we look at what is the maximum position it can reaches somewhere here and that angle if we called theta max then we have the relationship which is going to be taking about the position of the shaft with respect to the position of viper which should be known in terms of the position on the center called the resistor because the resistance soon to be a linear resistance which means resistance will keep on increasing with respect to this point as you travel around this is so let me shade this also because now i angles have flooded up the pictures so this is the register this register can basically be a bound wire you take a fine wire you wind it about in a coil and then you make sure the top surface is this so the insulation is removed so that the viper moves on it you can get the register you know you can have the flow of electric current take place um so

wound wire type they will give accuracies and linearity three to five percent of full scale this is the linear I think to five percent if you talk about full scale supposing the motion of the arm is two hundred degrees of some joint then five percent is quite a lot ten degrees its quit unacceptable okay so one has to do with one has to get better potentiometer and come back to polymer type conductive polymer type polymer type these are much better they can give you fraction of a percent so less than one percent of full scale there we are come down to a couple of degrees or degree of in terms of linearity there is also with the problem of noise because there is a moving contact and although the noise problem is much reduced in the conductive polymer type it has some kind of damp response on that compare to the wire wound wire wound of course also has discretization because You can go from one coil to another coil one winding to the another winding so there is a discreet change in the resistance take place where as the conductive polymer can be give a more smooth type of variation in resistance obviously the analog output is analog here this is the v out so if you need computer system go into

the controller this may have converted into digital type of signal or value and that there are devices available for doing that called a to d converters now v out obviously is equal to deta divided by deta max times vs this is by simple volt resistance resistance divider voltage divider and this can be written as some k times theta because vs is the constant theta max is the constant then we have this is the proportional signal to the position we can also write this as x times vs where x is the fraction over theta max so depending on how for it is travel along the resister we can have the voltage directly depend on the current

so basically the effective circuit that we have here is we have a voltage divider circuit with the total resistance of the film here is the r potentiometer Rp when I having one minus x times Rp here and x times Rp here and then iam taking the output from here and typically when iam try to measure the output I will have attach some equipment it I will have some effective loading resistance that will coming in here so in practice I will also have another resistance here is the let me called as the load resistance and this is what I am going to actually measure and this lets say vl so in using a potentiometer I can write down what my VL over VS is the iam going to write the voltage across the whole resistance the hole resistance being one minus X times RP plus the parallel combination of X times RP and RL so that is nothing but X times RP RL divided by X RP plus RL and the numerator we will have this part which is the parallel combination which is X times RP times RL divided by X times RP plus RL so this is what actually we will measure and if you say that there is some error compare to the ideal situation where you have

if you have RL approaching infinity then we will see that this will approach the output resistance the output voltage that we have talked about here okay otherwise you can say that the error is some x times VS minus VL so we can calculate that out and it turns out to be xtimes VS times RP divided by RL times x minus x square so this is the error assuming that RL is much larger then RP which is the case typically the resistance of the potentiometer would be of the order of hundred ohms two hundred ohms five hundred ohms where as the load resistance that we talking about will be of the order of kilo ohms from may be ten kilo ohms may be a good number to think on that will be give some errors which will be on order of a section of the percent right so one has to worry about this loading aspect of course by using operational amplifiers one can minimize this type of loading aspect okay(Slide time 26:35)



lets now look at another type of position sensors called optical encoder optical encoders are useful because they do not have any contact in the potentiometer you had a resistance and you had a wiper and that creates problem of noise in an optical encoder on other hand which have a disk which is coded so we have a situation we have round disk and on that disk what we are doing is here placing some diodes which will emit light and we are putting some sensors so let me put that side this is corresponding to some sensors here and on the other side which is not seen we have the source of light and this is the shaft whose angle we are trying to measure so what we want have is we want to have is some kind of coding on this disk this may be opaque coding parts may be transparent may be holes in that are the disk may be clear you may have some opaque sections of that and as a disk rotates because there is a light source on the other side and there are light sensors on this sides it will see some pattern of output

okay so photo detectors here so let me write down photo detectors and on this side we have LEDs leds are sources of light and by looking at the pattern on can find out what the position this is the basic idea behind a optical encoder and i said that the good thing is there is no conduct this here there is a air gap here there in no problem it doesnt lead to any kind of electrical disturbances now this could be in the rotary variety or it could be in a linear variety in the linear variety you have a coded linear segment and you will have sensors mounted on that in the same kind of and then you will have some patterns on the linear encoder so this is the rotary type this is the linear type in robotics mostly we are dealing with rotary joints other then there are some linear joints but linear encoder are most use in machines tools mc types of machine tools here we are going to primarily concentrate on rotary type but principle is the same and in fact we could think about linear one which is easier to draw and concept is same so we can illustrate with that so what i like to do is i like to show you that if i have say different bands here of information so i show here one two three for example you can have more supposing i have four bands in which the pattern is something of this thought like let me draw the four bands so one combination is that all of them are transparent

okay let say that amongst to zero output so iwill have zero zero zero zero as the combination then i say next combination is where one of them is opaque so then that will as a corresponding output of triple zero one and like wise i can put different patterns

okay so the pattern iam putting is a binary pattern here many of you may be familiar with this type of pattern i say what to be happen next you have this bit and have this bit and then you have all three of this notice that they are all unique patterns or combinations here onwards this will always be one and then you have here you have this one blacken this one blacken this two blacken then we have this one blacken then we have this along with this this along with black and all of them are black okay so these are basically combination zero zero one zero zero zero one one zero one zero zero zero one zero one zero one one zero zero one one one one zero zero zero one zero zero one one zero one zero one zero one one one one zero zero one one zero one one one one zero one one one one

so you recognize that this is nothing but binary counting and these are corresponding to sixteen different combinations and so on fifteen and sixteen okay so if you have four bands then so you can two to the power four times two to the power four the different combinations unique combinations which are possible and therefore if i have a disk which has got four such bands i can distinguish between sixteen different positions so this is basically called a absolute encoder absolute because it doesnt depends on what the position earlier was you can have a power failure and you turn on the machine again as soon as machine see the start on it know exactly what the shaft position is with in the accuracy of that sixteen degree so sixteen of course is the very cool figure you need to have much higher resolution so try to have eight bands then you will have two hundred and six possible positions and if you know that if something little better than one degree worse than one degree resolution that is not very good also

yes who have a question band meaning see iam having patterns of zeros are ones on the encoded disk so it depends on the how many photo detectors i have if i what ishown here is three photo detectors so this disk will be able to deduct eight different position of the disk but if have four of them have sixteen set possibilities if i have ten of them then i have thousand twenty four different possibilities of the position of the position on this rotary disc right each band is you take this drawn here and put it in a circle iam not drawn there because harder to drawn in a circle drawn in a straight patch so it is corresponding to the linear encoder but the same thing if you turn it around and joint this edge and of course because this will be a concentric circle diameter of this will be smaller than the diameter of that or put the other way out this beyond this will be the outer side of the edge so that you have fine decision here you have larger linear distance available on the rim so you can have more decisions that is the way to be done so is that clear

now okay (noise) coming so basically you require a at least ten such bands okay to give it to a thousand division of rotation to be which will be given better than one third of degree of a resolution there is one problem though this type of cut on i have shown you and that is that suppose it happen to read the encoder at say this instant okay or better if i

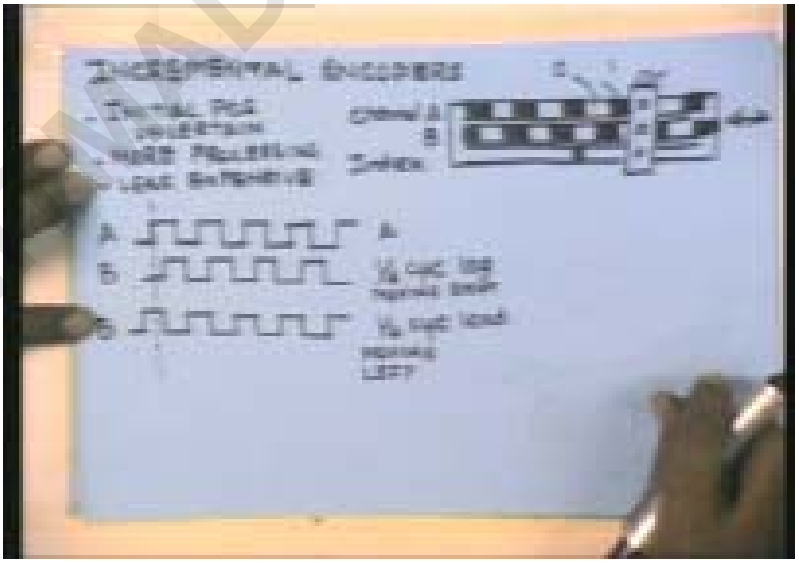
try to read this at this instant what is happening is i have zero one two three then my bit zero was one bit one was one and bit two and three were zero now in the next instance as the rotation is taking place the bit pattern is tending to zero one zero zero so basically three of the bits are changing at the same instant of time and what is if I if i just read at the transition then i will not be sure what the value i will get i may get zero imay get one i may get two i may get four any of this i can get depending on exactly how the timing the precision of the this particular edge is which cannot be predicted so this is the flow in type of binary pattern which can be overcome it can be overcome by something that is called a GRAY encoding

in the gray encoding if i look at the same four bands now the patterns will be different but there will be still unique combinations of four bits so here are my sixteen boxes along with each of the fact and i start filling out first one is all blanks corresponding to zero this is okay this is no problem then instead of simply having this on this like a hag in the binary column where iam allowing the bits to at the same time this has to turn on this has to come on and therefore we will not know what will happen may be both will turn on first before other one get turn off that will give us to a wrong value so we dont allow this to turn off here relieve that on we turn this one also mean make it opaque or whatever then in the next one we remove this first one so that we have unique combination so long we have covered this two bits we have four different combinations but there in the different order right but we have the same you can correspond different row up to this different rows up back so all of them are unique but you will still call this one two three four for code for three is now [noise]
okay is not three actually we starting from zero zero to fifteen as the sixteen combinations so basically we have zero zero zero one zero zero one one and zero zero one zero so there is a slight change in the pattern that i can so how will i continue to generate this pattern well i will take this on and i will turn this one on now because i could not have turn that off because i want to make one transition at a time right so i leave that on and turn this one on and then i will i will take these three [noise aha] i can do it yes i will turn this one on and this one on okay then i will take this one on this one is on and turn middle one off okay then the next one would be so the way i generate the pattern let me tell the secret of the that that i have every two iam alternate here

so i could simply generate it plainly so every two will be black and every two will be white here every four will be black and every four will be white so one two three four and i leave one two three four blank and then i have the next four right and then i take every eight of this so i have got one two three four five six seven eight and here i will take every sixteen starting from eighth position from one two three four five six seven eight and nine one words i got this is out okay you will notice that what i have done here is if you look at any pair of combinations next to each other we will see that there is only one bit exchanges so just look at that zero one one zero then i have zero one one one then i have zero one zero one then i have zero one zero zero then i have one one zero zero one one zero one one one one one one one one zero one zero one zero one zero one one one zero zero one one zero zero zero so pattern is different but they are all unique therefore if iam able to correctly interpret this combination then i can get the position correctly and i dont have the problem of transitions because any transition i look at there is one bit

changing either that bit would change or that bit it would not change the error would not be their there would be no furious reading coming in between that is very important so obviously this is not so intuitive because most people will be able to say something about binary code but gray code something that is you know difficult to refuse to so of course you can built a you electronic circuit which will convert your gray bits into binary bits you can display that so that is very simple so you take a gray bit three gray bit two gray bit one gray bit zero there we have binary three binary two binary one and binary zero and you notice that there is no difference in the most significant bit

so i connect this together this is my msb most significant bit then for getting the next one you need to give the XOR gate so i connect this to an XOR gate an get my d two thus every one know what a XOR gate is basically a logic device you know what is AND operation means two inputs are there both are in on the output is in on otherwise any other combination is not on similarly OR is when either of two inputs are on then the output would be on in XOR similar to OR except one combination when both the inputs are on the outputs remain off so i has to be straightly one of them not both so if i have device like that we use to convert your binary to sorry gray level to binary and of course vise versa to the little difference so one can easily built these kind of circuit in the hardware and attach it to the encoder which is got gray level inside inside you will always like to have a gray level output you can given a option of having either gray output or binary output okay so these are absolute encoder that you talk about absolute encoder you would like to see if you want to include the resolution of it then the number of bands keep on increasing then creating that disk which is going to have twelve bands or ten bands becomes say expansive process and that drives up the cost of the encoder also there will have so many more footed taxes and all the alignments and everything is crucial so the cost of these are much higher than cost of another variety of encoders which we call incremental encoders (slide time46:23)



okay the basic idea in incremental encoder is that we do have different tracks of pattern and different tracks of pattern let me draw them for you here once again you will have

some sensors and putting some space for the sensors iam covering the tracks and these are going to be divided in opaque and transparent sections parts so here is my opaque parts alternating with the transparent hats and part of it hidden under the sensor this thing then of course we have now we are not going to have multiple bands we only have two bands here
okay the second band is going to have the same pattern but displace five one quarter of the cycle so in the middle of black and the white these are sketched out this will goes here this will black here and of course next track starts there you will call a channel A and channel B in some cases you will have a third channel also but the third channel will only have one spot this called a Index channel
okay the idea basically is similar you have light source on one side and photo detectors on the other side assuming that light source is at the bottom i have three photo detectors here
and then this and then hole is mounted on what ever it moving so this is moving back and forth where as this is the text right what is the kind of output i will expect to see in the photo detectors well basically if i assume the photo detectors very small compare to the band with here and then even though the photo detector will get light or it will not get light and if it is getting light that say its one or zero whatever so we will get a pattern which is going to be basically a square type of pattern

okay so lets say this is channel A channel B is going to depend with relation to channel A is going to be quarter cycle behind because if it is moving to the right okay if it is moving to the right this black will come first assuming this is one that what assuming earlier this thing so this is corresponding to one so this is corresponding to zero lets say [noise] so this black will come in first then quarter cycle later this black will come if iam moving to the right so then i my pattern would be quarter cycle behind log this is channel B channel this is for right ward movement okay moving right

on the other hand if i was moving left you can see that what will happen is you will have this leading because now the holes are reverse are closed this part will come first then this part will come next if iam moving to the left so then our B channel will look different and B channel will look something like this this is quarter cycle lead moving LEFT right so if you have to see that iam talking a relation this leading edge let say so that this time this iam having upward channel transmission here in channel A in channel B it is not yet come little later in time it will come that why iam calling it log and here its already come quarter cycle before

so this this distinguishes tell me what is the direction of motion right from whether to look which way the lag is i will able to determine what is the direction of motion now to know the position what i have to do is simply count these if i count this number of pulses coming from here then i will be able to say how many pulse worth of rotation of motion i had this can be in a circle iam shown this is in linear band because easier to draw again but it can be in circle and then i can again have a pattern which matches which will give same type of output and i will be able to say what is the position from the beginning from some reference position now this is the problem you can say with this encoder compare to absolute encoder that is if you have to know what is the initial position that you started

out from an initial position ones you know that when you need to count up and down on whether you moving leftwards or rightwards and this is the function of the index pulse that is provided it helps you to determine where the encoder is in the beginning right there is a procedure that you will have to go through where by you move the encoder assume that this encoder rotates only ones lets assume that or it moves only this motion

in the rotary one you can have multiple rotation possible so in rotary one if you having a index pulse if you dont know after a twenty rotation you get the index pulse after two rotations got the index pulse so in a rotary on you will require some assistance from some other device or some other sensors to determine where you initial position was when you powered there are standard procedure for doing that you may use a potentiometer as a approximate measurement device to bring it to some known position and around that you have to move slowly until the index pulse comes you know precisely vary are then right or you may take it to a home position or extreme position and then start moving

okay this is my third time index pulse is come corresponds to twenty degrees whatever the case may be but one can do that so it requires the initial determination of positions so this is one of the problems the other thing is so here we we if power is ON we don't know where it is INITIAL POSITION NOT KNOWN UNCERTAIN it requires some other type of information to be able to find where the position is other problem is that it requires MORE PROCESSING right in the case of absolute encoder you just write that photo diodes it depending on what the pattern was you immediately know where you are here you have to do some processing like counting you have to determine the direction you have to see where are you moving and keep track of where you are

okay but these are of course much LESS EXPENSIVE because they are much simpler construction you only have two tracks and though the two tracks are enough for you to determine the position so we will look a little more about how this is accomplished actually in terms of the processing of the signals which we are getting in a channel A and channel B and how we can determine the position from the we will see in the next class thank you