ROBOTICS
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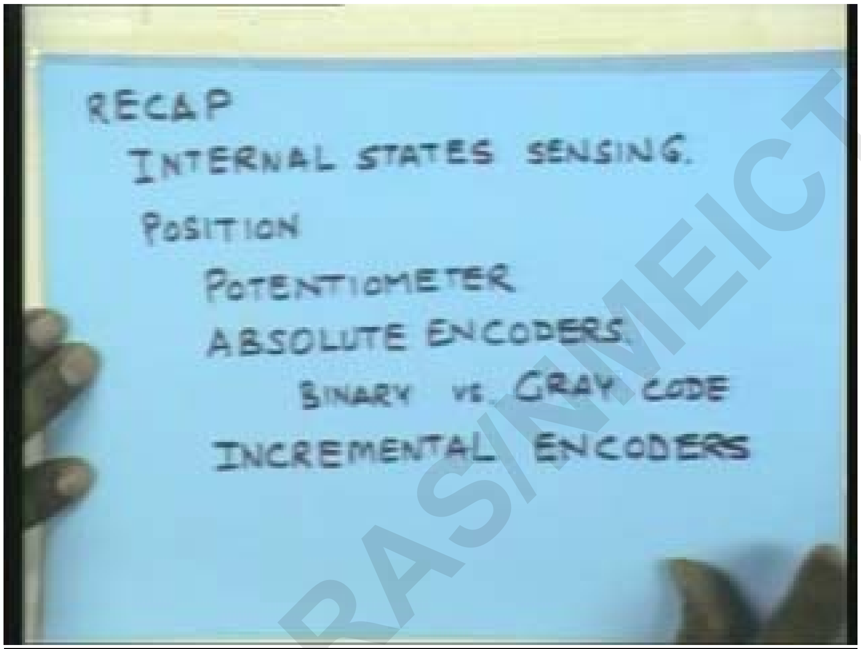
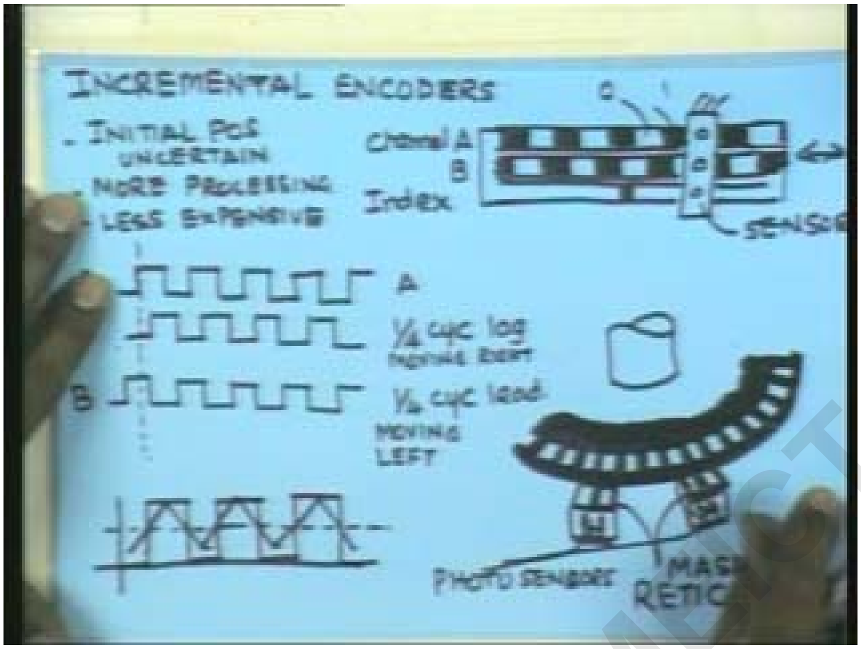
Lecture No-10
Internal State Sensors Time(1:20 min)

So let us start with the recap of what we have done last time (Refer Slide time 1:39 min)



we recall we looked at the internal state sensing in robots an internal state sensing is basically something that assist in the basic movements of the robots and for internal state sensing started looking at the position sensing so here we are interest in knowing the position of the any joints and one obvious choice is what everyone would familiar with is the potentiometer a potentiometer is simply a variable resistance and if the resistance changing with the positions we can find out what the position is by measuring the resistance in someway or using as a voltage divider pointed out to you a fact that could be a loading effect which has to be taken care of then we looked at the absolute encoders

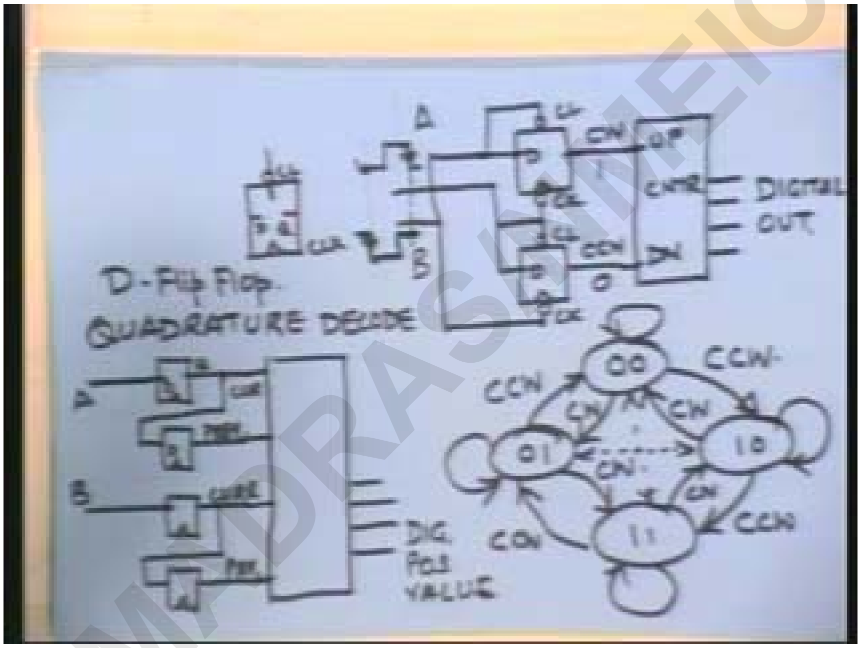
absolute encoders are essentially optical encoders in which there is no contact between the moving part and stationary part and therefore they have the various advantages of that they dont clown in mechanical term the shaft we looked at the binary code versus gray code okay and then we started to look at incremental encoders okay this is where we were and now lets continue with the material (Refer Slide time 3:43 min)



okay so incremental encoders we did we looked at what the basic construction is the basic construction we have two channels of pattern latched out on to a disk clear portion and opaque portion and the two pattern are offset with respect to each other by what we will say the quarter cycle quarter cycle you know this is one cycle form beginning of the black to the beginning of black then in that one cycle we have this shifted by one quarter of the cycle and depending on which direction the strip is moving with respect to the sensors these are sensors here

which are basically photodiodes and photo emitter and photo sensors and if you look at output of various diodes photo sensors here then we see that channel A will give as a square wave if the sensing element is very much narrow or then the pattern that we have so we can get a square wave here i look at the B wave B channel output then it will be logging behind one quarter cycle as shown here or it may be leading the channel A by quarter cycle depending on which direction this is moving now we can imagine that this is not a straight line but in a circular disk so the shaft would be somewhere here and you have a disk which goes around as shown only one set of pattern here and one set of pattern disk is good enough all we want to do is instead of putting the sensors in a line we can displace a sensors so that they are quarter cycle displaced that is done by putting two mask so what i shown here is mask or also called as reticle and these are aligned with respect to each other and they are offset by quarter cycle they are not next to each other they dont have to be there can be anywhere but there offset by the quarter cycle so the output that we will see from these two sensors will be similar to what i have shown you earlier and sensors are kept below this so this is the photo sensors and depending on whether the masks are align to each other or not we will get full full light to the sensors or partial light to the sensors if they totally offset then we will get no light so actually if we look at it you will expect that output of this photo sensors will be some kind of a triangular wave because you have all possible situations where you have fully align poles with respect to the mask and so we get the maximum amount of photo diode current or if you have partial one then we will have partial amount of light come in and if we totally obstructed then there will be ambient light which will give a some output which will be non zero possible now you can get a square wave one can simply take a thresholds and say you say device like a comparator so any anytime the signal is above the threshold you can get a high and whenever it goes below the threshold so it become zero

so this way you can generate a square wave and thats what we will need now what do we do after we gotten a output of the two channels of the sensors okay when we get two channels output then we want to first of all detect what the direction of motion is and if the motion of is in one direction then will add the count if it is in the opposite direction when we should subtract from the given position so for that we need to have two things one is that we need to able to detect direction and that we have able to do counting so for direction detection one can use flip flops (Refer Slide time 8:28 min)



so if i draw a typical flip flop say this is a D flip flop D Flip Flop will have a data input and an output few output it may have a clear or it may have a clock

so what we can do is we can take our two channel of input an one channel of input take here and i take it here and i have one of my flip flop here and another of my flip flop is here so iam going to connect this to the input the D input of one flip flop and also to the nark here so i put a circle in any of these input it has the meaning of reversing the complementing the input so if without the circle if you gave a height to this particular terminal then it will clear the output but if i put a circle and i gave a signal lows signal now the low signal will clear it but high signal will not clear it so therefore these circles that iam drawn here way that mean that you would input is complemented or it will act in the other way similarly i take the other channel output and i connected to the other input and also the other clear so this is clear this is clear this is clock and these are the two input and i have my input waves from the two channels channel A and channel B coming here they are obviously offset by ninety degrees phase difference so what will happen is one of them will be low or both of them can be low or both of them can be high depending on what is the phase difference that we have and the circuit it shorts one of them will indicate to us the up direction of clockwise direction and another one will indicate to us is the counter clockwise direction and then we can take this two inputs to a counter device

to understand the operation of these circuit basically you have to look at each of the flip flop the way the flip flop will work is when the clock is coming when i show the clock input as a triangle here that means it is going to look at the only the edge when it is going from high to low because i have the circle also whenever a clock goes from high to low whatever input D is get latched on to the output okay this is what you have just remember so if we look at the transition which are important which is that when B channel is going from high to low at this particular instant of time we can see that A input is zero at that point so if you look at D we have connected the B to the nark the clock of this nark clock of this as goes down this D flip flop will act and will see that input from A is zero so is going to put a zero on this output similar if i want to look at the output of this particular flip flop i have to look at when this clock is going down and this clock is connected to A input A input down going edge is here and therefore corresponding to that when i see my B output is high so my B output B output from the encoder connected to the input of the D flip flop here and therefore when the clock A goes down this gets latched on and this get the value of one so you will you can convince yourself by looking at the circuit where this both this output will be complementary and whenever one is leading the other you have one output whenever the other one is leading then you have the other output this can be use as a up and down signal for counting purposes then this counter is a simple counter which will keep on counting whenever there is a pulse coming from either of these channels you can connect either of the A channel or B channel here then counting up and down depends on up and down input that we have here now this way

if you have five hundred lines or mask on the disk you can decipher five hundred of a rotation as a degree as the measurement of the angle it also possible to look at finer changes in the state because you know that we have the state zero zero here then this remains zero and this will become one and this remains one and this also becomes one so you have all possible combination you can have zero zero you can have one one you can have one zero and you can have zero one this are the four possible states that we have i know that if i going from zero zero to zero one okay then iam going counter clockwise similarly when iam going from one zero to one one iam going counter clockwise and all of four this four of this transitions in this order means counter clockwise rotation let say if the concession is from one zero to zero zero then its corresponds to a clockwise rotation similarly we have other possible clockwise rotations okay if one zero remains one zero then of course there is no change in position not enough change in position

so these are also possible but they mean that there is no change in position obviously a zero one going to one zero or vise versa is something that it should not happen unless of course there is some problem right so these are not allowed transition these are illegal transitions all others are legal transitions and if we look at each of the transition then you can see that you can take one cycle and we can divide the cycle into four distinct portion so we can resolve four time as many positions so if we had a five hundred count encoder when we can get two thousand of a revolution this viper this way so this is called quadrature decoding [noise]

so quadrature decode and basic way you do is you need to know what the current state is and what the previous state was and so a simple circuit will do this for us we again have four D flip flop and so we have one input coming here is one of these states and then we have this output coming here and this output is take as a input to the next flip flop so these are the D inputs and these are the Q outputs and this is the other output similarly we have for the third flip flop we take this is channel A this is channel B and similarly we take the output of these put into the input of these and then we have output of these so we have four possible output coming out here what are these representing A input connected to b A channel connected to D input when the clock comes we will gives us will latch on to whatever this A signal was whether it high or low this is the previous value of Q which is the at the same time all the clocks are tie together at the same time whatever the previous state was latched on to this so this is the current position this is the previous similarly this is the current B channel and this is the previous B channel so knowing the current in the previous we have the information about what transition has taken place and i can put this inside i can just configure memory in that and take this four as addresses so we have sixteen possible addresses and each will corresponds to plus a count or minus a count or plus a zero or minus a zero or a illegal operation so illegal operation can be flagged otherwise this can use to give us R position so this is the digital position value from the two channel input A and B we are now able to despiser the complete state changes and therefore we can do a quadrature decoding on the encoder okay
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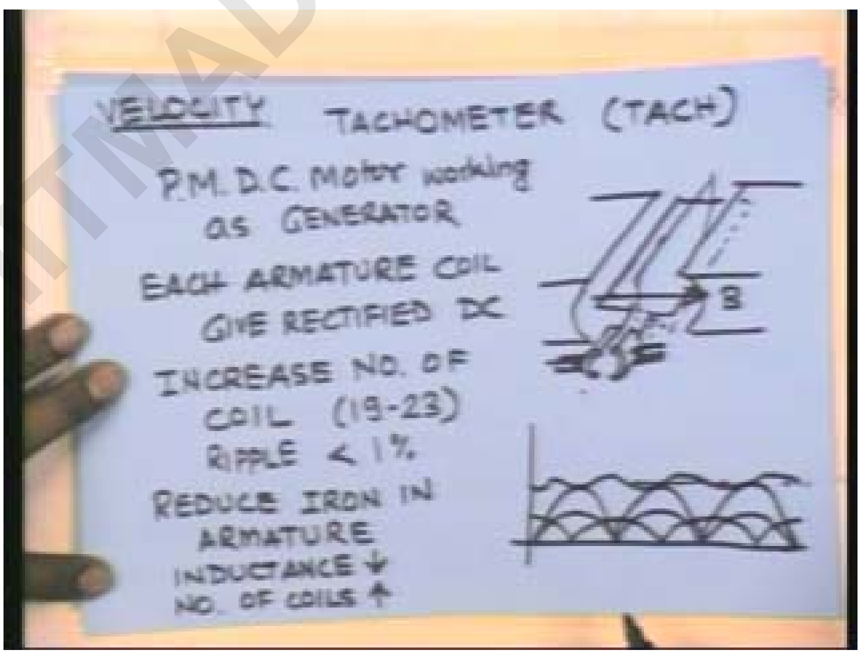
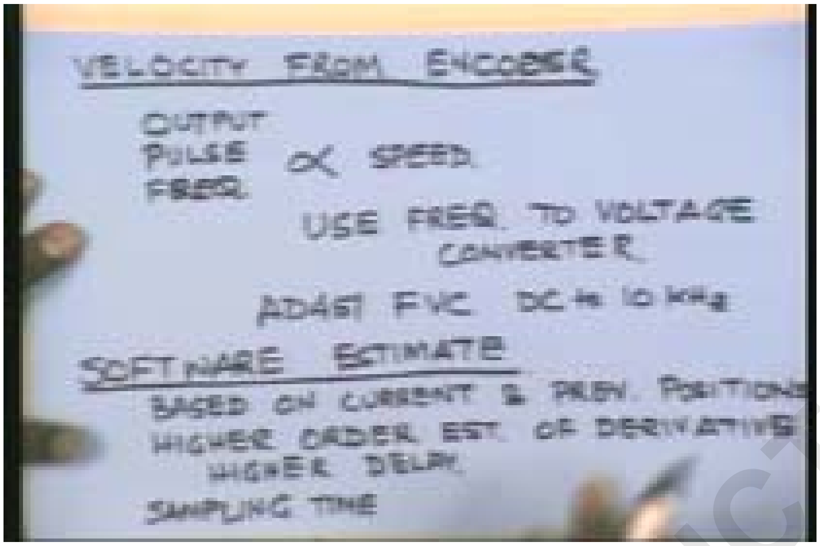


so much for position lets move on to the velocity and for velocity what is commonly used is a tachometer also call it (TACH) you would all be familiar with tachometer techometer is not but a permanent magnet pm dc motor working as a generator okay permanent magnet DC motor will simplify the magnetic field and you have a set of armature connected to commutators and we have some kind of coils connected to this and you have carbon brushes which are connected to this brushes so this is my magnetic field so what happens is when this is rotated the armature is rotated we have a voltage that develops in a coil because the coil is moving in a magnetic field and the velocity times of magnetic fields strength gives as a voltage and it also becomes of course on the angular position of the coil so if the coil was inclined then A sine deta terms comes in so the output that we expect of course one of the thing you have to notice is that the polarize gets reverse after hundred and eighty degrees so you dont allow a full sign wave to develop but what we do is we have rectified sine wave that is generated

okay so each curve each armature coil gives rectified DC okay now if you look at a average value or aromas value or the peak value this is going to be basically a is proportional to the velocity of the angular velocity of the rotation of the particular shaft so i can use this device in a robot joint and as the robot joints moves i will get a voltage output which is going to be proportion to the velocity i can use that now single coil gives as this is called a ripple this is not a constant value of that speed or angular velocity may be constant or output is not a constant output is varying so what one can do is we can addition of coil suppose instead of one coil i have another coil which is perpendicular to that then i will get another output from this particular coil

okay and that output now perhaps this output will reduce because the coil is now smaller i have this and then i have another output which is coming hundred and eighty degrees out of ninety degree out of phase and therefore and when i add two together iam going to get a output like this so you can see that my overall output has come to be much more a constant value then what i had okay we can we need to do is to increase the number of coils for more uniform output proportional to the angular velocity this is how tachometer design is different then a motor design okay in tachometer common to have (ninety to twenty three coils) and that way you can reduce the ripple ripple voltage can be brought down to less than one percent if you use so many coils

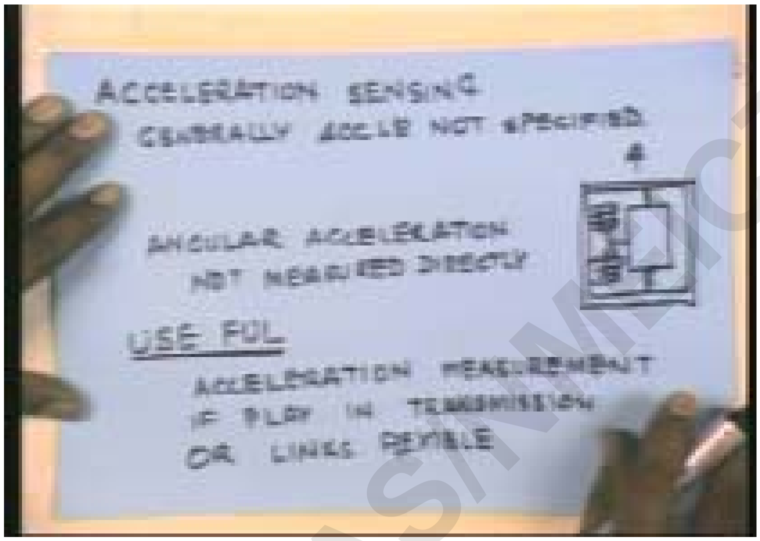
so this is fairly good indication of the speed what can be done further is one can reduce the iron in the armature so you can also reduce iron in armature and the effect of that is basically that reduces the inductance inductance goes down and you also have more space available for putting the coils so the number of coils can be increase so you can have a moving coil type of tachometer in which iron is either very little or no iron and that can give even better output okay now they are some other way we can to find velocities we already most of the robots we already have a encoder encoder is the most preferred way of mashing the position because it give you a sufficient accuracy compared to A in fact potentiometer (Refer Slide time 25:00 min)



so why not get velocity from encoder output okay this will be more beneficial because we want to add number sensors we can just take the output of the encoder and then we use it as velocity how do you do that basically we know that the output pulse frequency frequency is proportional to speed so it use a frequency to voltage converter and such devices are available for example there is some analog device ad four fifty one is a fvc frequency to voltage converter and it basically works from DC to about ten kilohertz if it provided input from DC to ten kilohertz we review a output proportional to the frequency that we can use directly as a velocity measurement

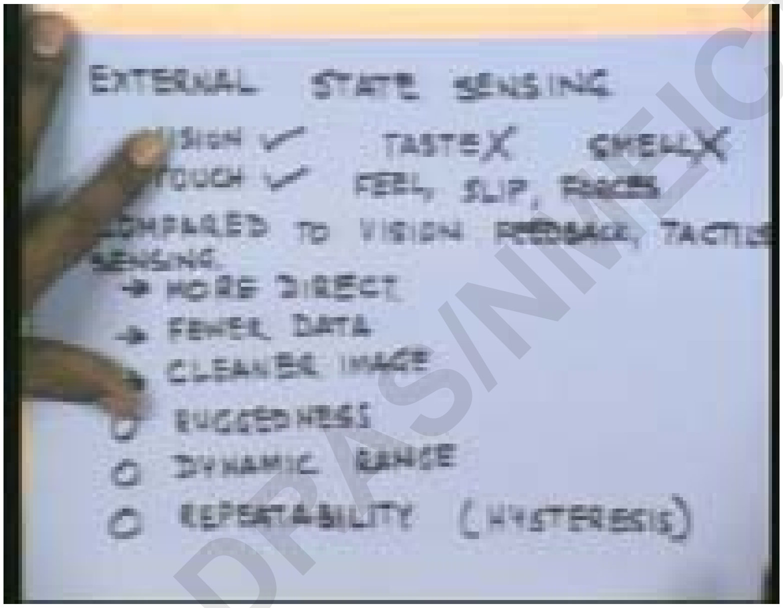
another way possible is you can find the soft in software you can find the velocity so you can estimate using software because we have the pulses coming in and then we can see we can do couple of different ways we can look at the current in the previous one so you can based it on current position and previous position and okay if you do that and then we get the estimate of you know the time difference between them and you know the position difference when one can estimate the derivative and that gives you a value of velocity the problem with that is there is some amount of delay involve because we are going to now look at the present position and look at previous position and so that what we are estimating is velocity

which is somewhere in between this is not exactly the current velocity and if you use highered estimations of derivative per order estimation of derivatives derivative rather is going to introduce higher delays higher orders will actually look at the previous position and the previous position to that and therefore again the delay keeps on increasing and this could have a harmful effect in the control circuit that you will have control loop doesnt like time delays those dent to make it the system unstable another thing to watch out when we doing software estimation is actually what is the sampling time we using if you use a very small sampling time then what will happen is that you will either have it pulse or either you will have no pulse if you have fine enough interval then either there will be a transition from encoder or there will be no transition from encoder if there is no transition from encoder speed comes out zero if there is a single pulse that has come that means there will be some large velocity value so that is not very very satisfactory you will like to choose a time period which is larger then that but if you choose it too large then you may violet what is called sampling here on which means you are not going to see all then one in change of velocity if you take a interval which is very large then they would be changes in the velocity which will not be captured so this has to be done judicially judiciously and you can chooses a proper time interval which will be suitable for the particular application (Refer Slide time 30:00 min)



then in sensing internal state sensing last thing that we can talk about is acceleration [noise] so if you look at the robot task generally we dont have a specification on acceleration we have a specification on the position and we have a specification on the velocity in terms of the task we are trying to do or we will making the robot do we can have it a position movement or you can have a trajectory in which say that speed has to be maintained certain such value but acceleration is not generally specified okay so generally you can say acceleration not specified and therefore position and velocity sensing would be generally adequate but in case you need to measure the acceleration then one can use the accelerometer accelerometer is basically a mask suspended on springs and depending on how the whole housing moves the mask get displace with respect to the housing and that can be measured let say by you know have a lvtd you can have right core here you can have some coils and you can look at the output of these coils and one can decide where the position of the mass is which can tell you the study value of linear accelerations if the think if the acceleration in this direction then will be displacement of the mask in opposite direction due to nestle fact that can be measured you can estimate the acceleration however angular estimation is

what is important and that is not directly measurable one can put multiple accelerometers in different directions and one can look at the various component of acceleration and then one can find out what is the normal components and what is the angular acceleration that way can be estimated but there are no good sensors available which will directly measure the angular acceleration now acceleration move can be useful in some circumstances so i will say use ful this is due to fact that if you have a if you look at typically any of the joints of the robot then you have a activator through a gyre box which is going to try to move the links and then the link will move so if the gyre box that we had some play in it then the actual movement of the arm is not reflected in the sensors which will be put on the motor shaft right if there are place in the in the transmission or if there was a flexibility in the link then the actual position of the end factor can differ from the what to be sense by the sensors and minute space you can be it it will be useful to have a accelerometer or acceleration measurement if play in transmission or if links are flexible okay but this kind of this you would say more experimental or research type of problem then routine problem in the industrial robotics industrial robotics usually does not use any accelerometer feedback (Refer Slide time 34:40 min)



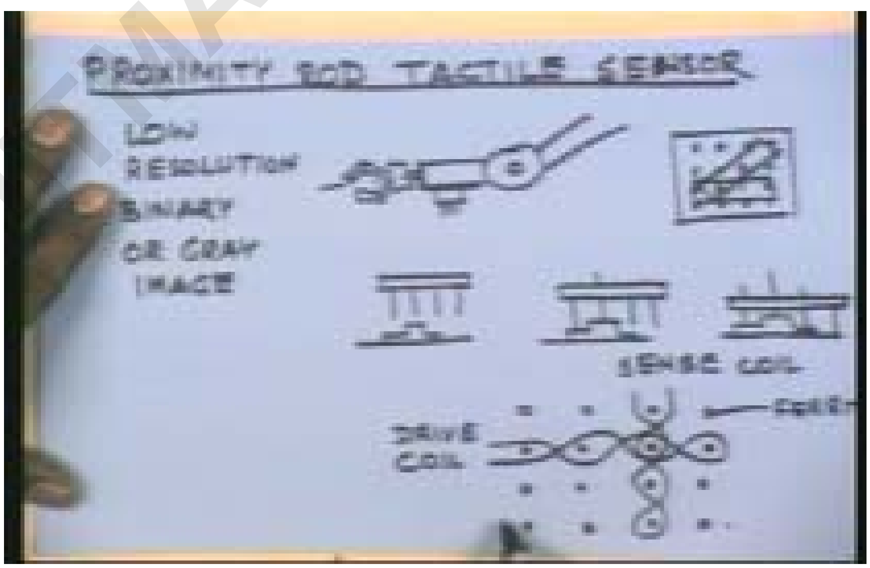
okay having seen all this different ways of finding the internal state lets now look at the external state sensing i had already went to my introductory lecture i had talked about this and anything that helps us in interacting with the environment you basically called as a external state sensing so if you compare a robot operation with respect to what we are capable of sensing or we have sensory organs and we have vision okay we have a sense of taste sense of smell touch and so and so forth right

so vision is used in robotics taste and smell are not used what about touch it is not very much used but it is actually quite useful if you look at this it has got the object feels like whether the object is slipping in the grip these are important things forces movements temperatures this kind of sensing will be useful to get some useful information about the object this can help us to it will help the robot in performing its task better so compared to vision which is actually use quite often feedback we will call this tactile sensing
okay the advantages that this is more direct what do you i mean by that iam try to sense a part may be i want to know it fell like whether hard or soft where iam touching is hard or soft or what the orientation is this is the kind of information that iam looking for a tactile sensor will have sensing element which will directly touch the object and therefore you

have more direct feel of the object compare to the image of the object image of the object may not be able to tell the hardness of the object for example then typically a tactile sensors will have fewer data okay this is the advantage in the sense that in a vision feedback typical vision image may be five hundred by five hundred pixels or it may be thousand by thousand pixels high resolution that means you talking about hundreds and thousands of data come for each of the pixel elements what the intensity level are exedras exedras you have to deal with huge amount of data and this is of course used and we will take it up later in the course and some details but in tactile sensing

typically you will have only a elements which will be in tens or hundreds rarely in thousands but more like hundreds you have much lesser amount of data to processed and therefore you can do a real time processing of a data which can be used in the operation of the robot and then of course you have a cleaner image if you can call that a image which is from sensing elements because the background is going to be much clearer here when you take a camera short then it is not always possible to have a uniform background the background will contain images of the other things which are in the background could be other machines could be moving people and therefore it causes a problem in terms of separating what is the useful what the object is from the background itself where as in a in a tactile sensors this is not going to be as much of problem because you are simply or going to feel the object and therefore the background is going to be all zero you can say okay in terms of problems well recognizes one issue here and

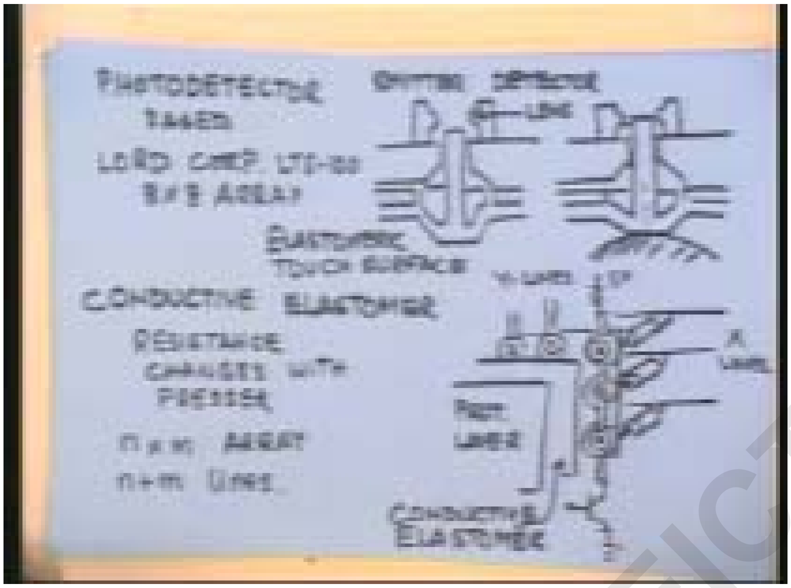
this is the issue because the tactile sensors is going to touch a object it is going to be physically interact with the environment whereas the vision sensors there is no touch there is no interaction on the force level so recognize becomes important dynamic range is another issue usually dynamic range of tactile sensors is going to be much smaller also which means you will not able to get as much data about some aspects of the feel another issue is repeatability usually the repeatability also much poorer you too (hysteresis) if you have hysteresis this elements then the repeatability suffers(Refer Slide time 40:43 min)



okay look at some of the tactile sensing so basically if i look at one which is based on proximity one is called proximity rod tactile sensor okay the basic way these works is that you have a robot let me just draw the last link of the robot on which some gripper connected okay some orientation then at the some where down in the arm i will put the tactile sensor from showing tactile sensors with some rods sticking out and this is basically a two dimensional array of of rods so if i have four cross four along the vertical direction then i have these sixteen little rods hanging out from there the basic way it work to very simple supposing you having a object which has the contour like this and then we have the arc iam enlarging now this portion where the tactile sensors works and these are the pins picking out of that we will ask the robots to approach downwards okay align to the table surface so if i come down a little bit then this is my object now this have been started touching the arc this has been about to touch this been not yet touching and this is not touching at all so this has been pushed up

okay if i take it further down then this is my object here now this is touching this is touching this is touching and only this just about start to touch the tables surface and therefore iam going to get some extension here some extension here and no extension here so we can we can measure the extension and these things you know what is the profile of the object where the object is versus the table is okay so this will gives as low resolution binary or gray image okay we can see that how we are talking about very small resolution it can perhaps tell you if the object is laying like that versus if the object is laying like that because then you will see which of the pin that which i have gotten even if it is was a binary input binary output from the particular pin you will have some of the pin will be pressed they will be registered as on and some will registered off and then find out what the orientation must be and then what will done is the robot will be ask you to approach the object knowing the position and the orientation according to the orientation of the object

if you want to do a gray level sensing then we can have a scheme let say you are using pins which are extending upwards now wherever some of these are extending upwards some of them were are not you have array of them so what we do is we put a drive coil around each row this is simplified way iam try to show that i have drive coil i can put sense coil which is perpendicular to that this is the sense coil and these are plunders which are sticking up may be ferred materials and as i can sequentially drive these coils one at a time and then i can ones iam driving one of them i can sequentially sense the coils here so depending on the ferred rod height i will get a sense signal it can tell me how much the ferred and how much of the this rods has been proximity rods has been pushed so this can give me a gray level image we can distinguish between the different height of the object in different places right (Refer Slide time 45:54 min)



now similar to this we can have number of other possibilities we can have one let say this is photo detector phase okay what is will consist of is a elestomeric touch surface okay you got the extension this is the shape of that elastomeric okay there is a basically very light firm type of material here and you have a rigid support structure here and then what you have is you have photo emitter and a photo diode and what iam showing here as this are the lens part this is the emitter and this is the detector okay now supposing there was a object here and we load this type of sensor then what will happen this will get compressed and this flendger will go down further my photo emitter and a photo detector are here

okay now we can see that the light seen from here is partially uploaded and therefore we will get lesser output and this can be then use to see this particular position corresponding to this sensing elements as now been depressed this is actually a commercially available device and this commercial available device is available from one company called lord corporation okay product name is lts one hundred and gives you eight by eight array of sensors

okay a similar type of approach can be used if you use conductive elastomer okay in this particular device you have productive layer of some plastic then you have layer of conductive elastomer okay then you have the sheet which is basically a circuit board ecd which has some pattern made in copper let say and so there is a hole array of them connect them to the top to some power supply to a full of register this is five volts at the bottom you can have some control so supposing this connect it to a transistors with some control inputs so this pcb layer is rare now the center dots here are connected to let say diodes here and this is connected to some kind of grid and these are connected to y line let say and these are all x lines okay you get the idea basically so what is we have this electrodes here which are concentric and on top of this we have the elastic conductive elastomer depending on how much of the pressure is put on the device the resistance of elastomer okay changes with pressure okay if you changes the pressure okay then ones again we can do the same type of scheme where by you energies each of these in tern y lines and then you sense or you energies the x lines and you sense it on the y lines the voltage is which will tells you which of these will be able to take a particular element TACTILE element will be able to see the output of the particular tactile element so once again give you a image low resolution image of the object that you are going to grip

using this type of a surface one thing to notice to all this designs in which you have to erase is that if you have n by n m array and if you try to sense each of them separately then you requires n times m pair of wires coming out of the device so if we are sixty four elements which is seems to be common when you have sixty eight times to or a two sixty four sixty four lines coming out of it whereas when you do it scanning like this then you have only n plus m lines required this becomes important because this device most likely to sit at a gripper area and therefore the entire sixty four lines if you have lot of this lines cables will run through the robot which will be a problem we will get twisted you will get thrust it will effect a movement of the robot if it is very stiff and therefore the detection of line here is quite desirable so i think this is the we will come to end of this lecture.