ROBOTICS

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Lecture No-39

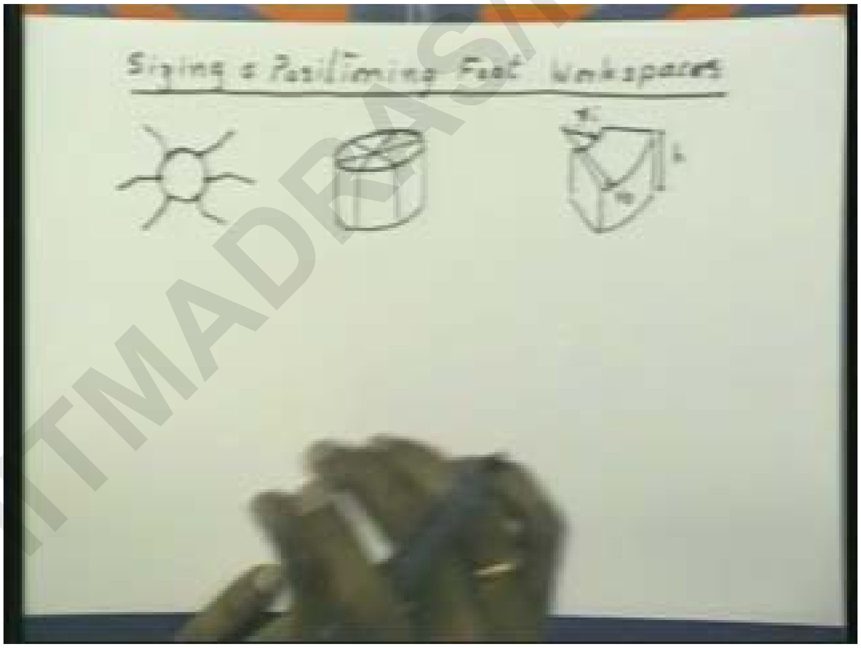
Yeah um yesterday we started discussing the design of a walking robot for a specific purpose this is one of the case studies we will be seeing in the course

the purpose of this particular machine is to move in a nuclear power plant where there is radio activity and do some very simple operations like monitoring and maintenance

the requirements that are posed for this machine were um discussed in the last class and we came down to decisions like the number of legs and the arrangements of the legs

how to now size and position the workspaces of the feet that was the issue we were discussing in the last class

so to give you the background to that the machine has a body with six legs arranged axial symmetrically around a vertical axis (refer slide time 00:02:09)



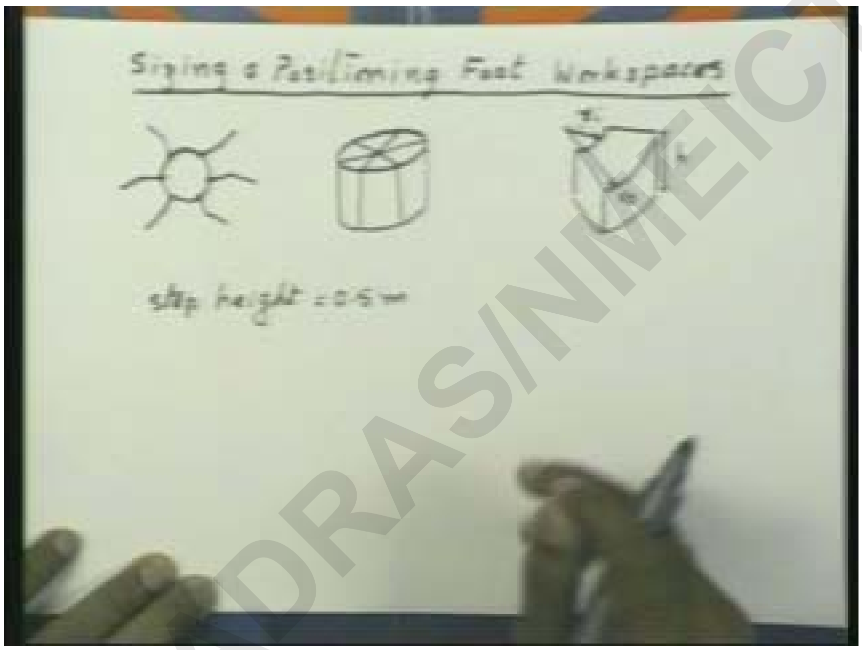
then the natural shape of the workspace of a foot would be a solid sector like this sect of a cylinder like this

but remember that we are placing the we may have to place the actuator which rotates the whole leg away from the center of the body and so we may not be able to access the innermost regions of this sector the that may have to be followed so if we look at the workspace it would look something like this an annular cylinder a hollow cylinder with inner radius r i and outer radius r o r outer and height h

now how do you position this on the body once you position one all others are arranged symmetrically similar

now how do you decide this now in order to decide this we need to consider some of the specifications which were drawn up at the beginning

one of which was the step it should be able to climb at least zero point five meters
(refer slide time 00:03:30) it should be able to climb



another was that the stroke of the foot should be at least five zero point five meters
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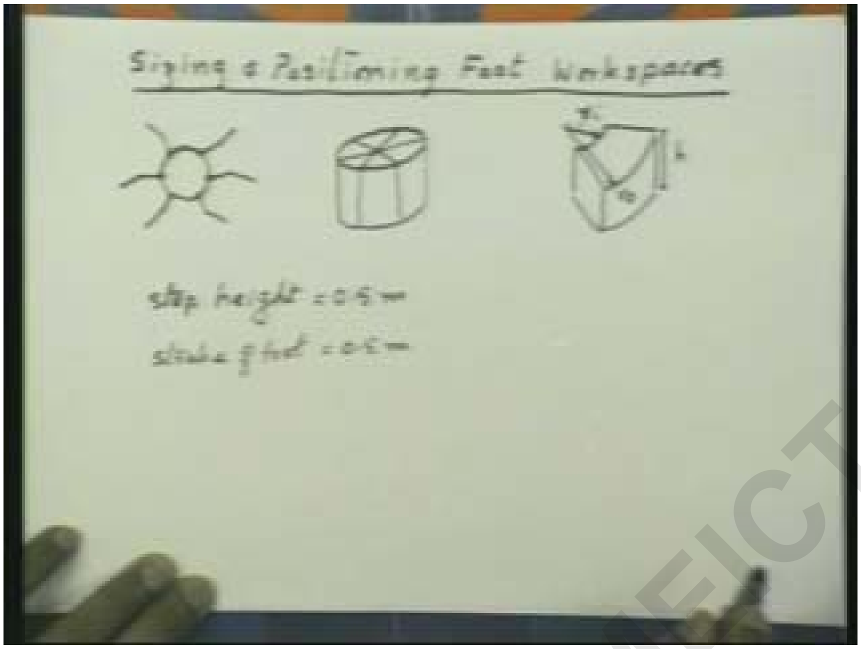

this is in order to be able to step across some obstacle on the ground smaller obstacles on the ground

now based on this how do we determine the size of the workspace will determine it in such a way that the total size of the leg eventually should be small right

now in order to determine this you need to consider the way in which the machine would be walking

first of all let us consider how it would climb a step there are different ways we can make it climb the step

if we look at a step we can imagine that the body would be something like this one for a set of legs up there like this another set of legs down here like this this quite possible right you tilt the body and you reach the step and then climb up
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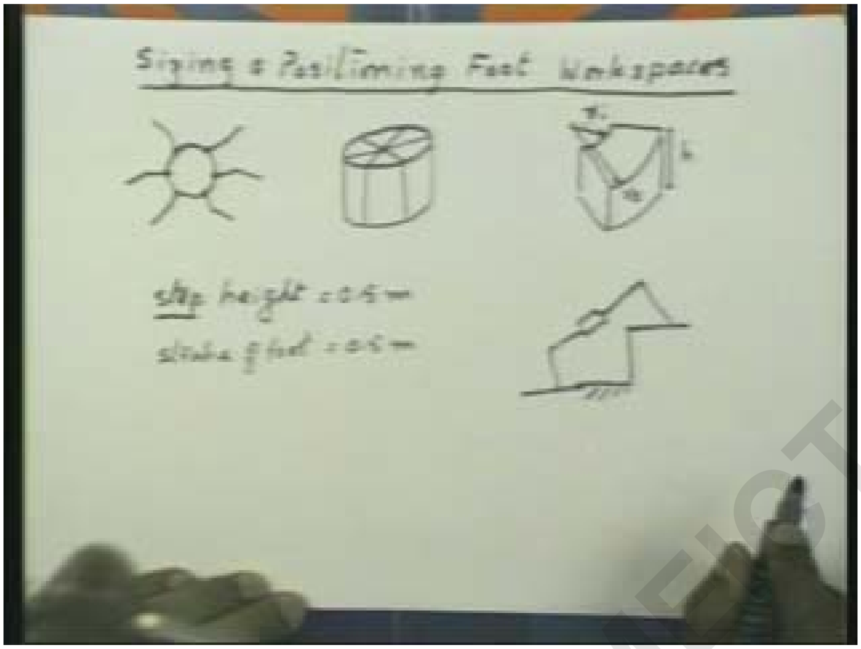
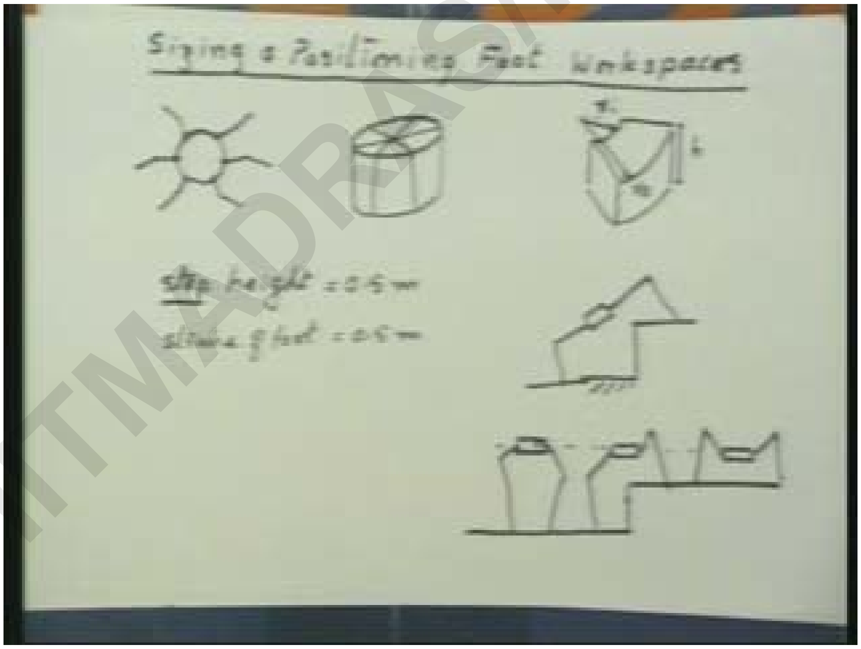


while doing that of course you have to ensure that it is stable fine but a different way of climbing is the following which is actually even simpler right (refer slide time 00:05:26)



so in this the way it is climbing the height of the body above some datum remains fixed in spite of climbing on to a step right that doesn't change at all

you just place the feet at the appropriate height as you climb so the manner in which it climbs would be almost similar to the way it walks on level ground only remember that while it comes here when it lifts the leg in order to place here you have to ensure that the leg or the body doesn't hit the stair that has to be taken care of

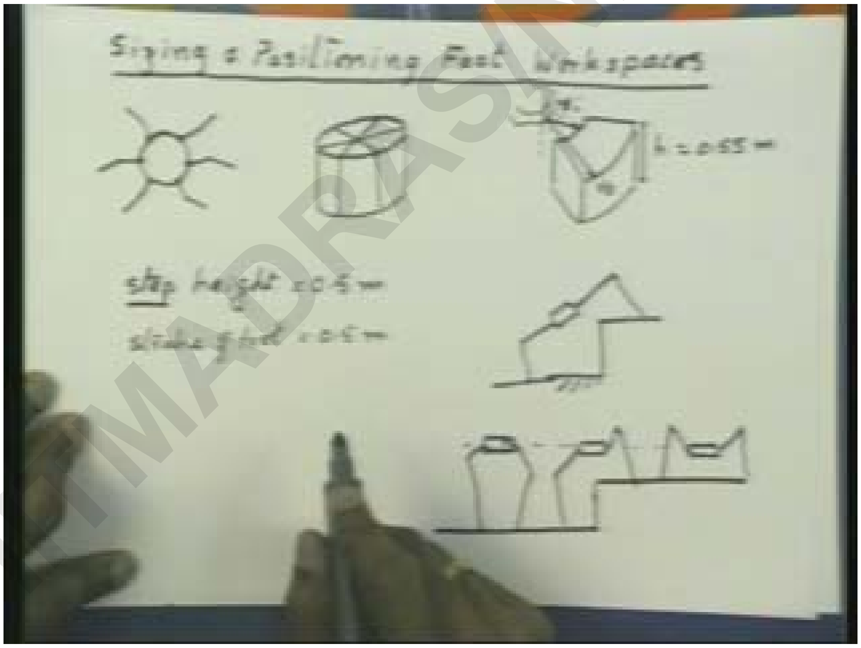
but we can regard this as a broad approach for climbing so the difference between this way of climbing and this way of climbing is that here the body tilts here the body doesn't tilt right

in order to be able to climb like this this point as well as this point has to be part of the workspace so the minimum height of the workspace that you need here is the height of the step itself that you should have alleased that

so we took this as zero point five five meters so in order to have some deep

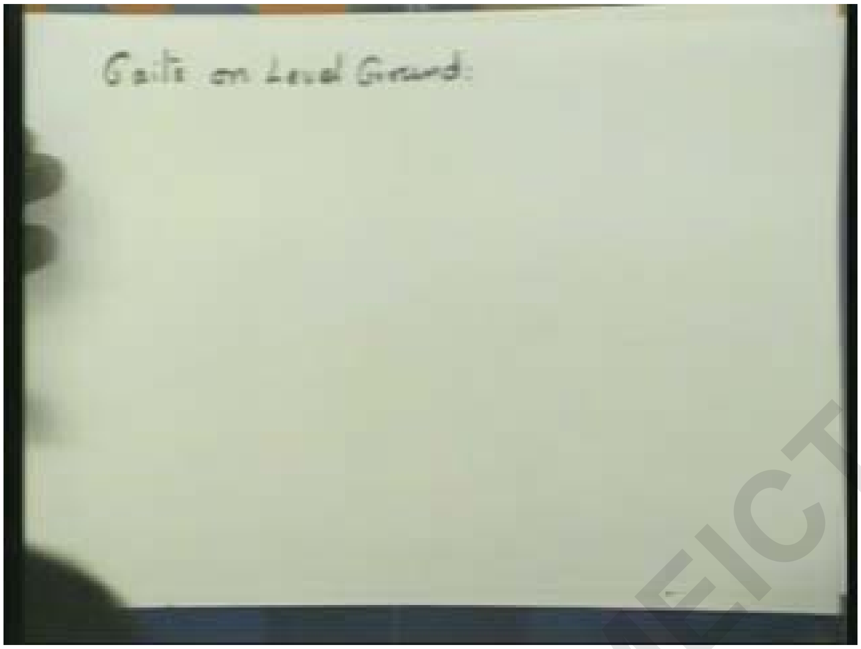
the height of the workspace is decided like this fine now if you look at the body in relation to this workspace this particular swivel actuator the access would be somewhere here and the body could extend beyond like this fine

the body would be something like this so the swivel actuator will rotate the leg in order to access this workspace (refer slide time 00:07:20)



so for the moment let us not consider like that let us consider that the this particular simple picture and see how we need to now size this workspace these two dimensions r outer and r inner such that a stroke of zero point five metres can be accommodated within the workspace fine

in order to understand that we have to see how the machine would walk on level ground (refer slide time 00:08:05)



for a six legged machine there are many types of gaits which are possible i will just show two very simple gaits for which this machine was designed

the idea is that once it is able to walk with a particular gait it should be able to walk at least with some slope with the other gaits

so what we will try to ensure you is that it should be able to work with one or two gaits important giats with the zero point five meters slope

so two typical gaits are like this if you think of the body say the alternate legs there is a leg here there is a leg here and there is a leg here which are suddenly lifted
(refer slide time 00:08:58)

these three feet are on the ground right and the body is getting propelled forward on these legs so this is what is called the thaipar gait

the feet forms a triangle on the ground right (refer slide time 00:09:29)

if you take the three feet on the ground the convex hull of that that is the minimal convex head which includes those three points is the triangle fine

now this minimal convex set the convex hull has an important role to play in stability of the system and if you look at the central mass of the system which is somewhere here

this system the necessary and sufficient condition for this to be stable on level ground is that the projection of the central mass downwards falls within this particular triangle called as the support pattern

another way we can calculate this is try to calculate the reaction forces on the three feet coming from the ground

if any of them is negative it means that the system is going to topple for example if these this is negative and these two are positive it means that the it is going to topple in this direction

this can only happen if this particular center of mass is on this side if center of mass is inside the triangle it will not topple

so stability has been quantified using this concept that distance of the center of mass at any point from the triangle edge edge of the triangle or the support pattern is called the stability mass

so if your support pattern lets say there are four legs or five legs on the ground lets say five legs are on the ground

the convex hall of these five legs is this quadrilateral (refer slide time 00:11:09)

the central mass lets assume is here the shortest distance from the central mass to the edge of the convex hall is regarded as what is called the kinematic stability margin

if its moving in a particular direction the stability margin in that direction there are two one in this direction one in the opposite are called longitudinal stability margins
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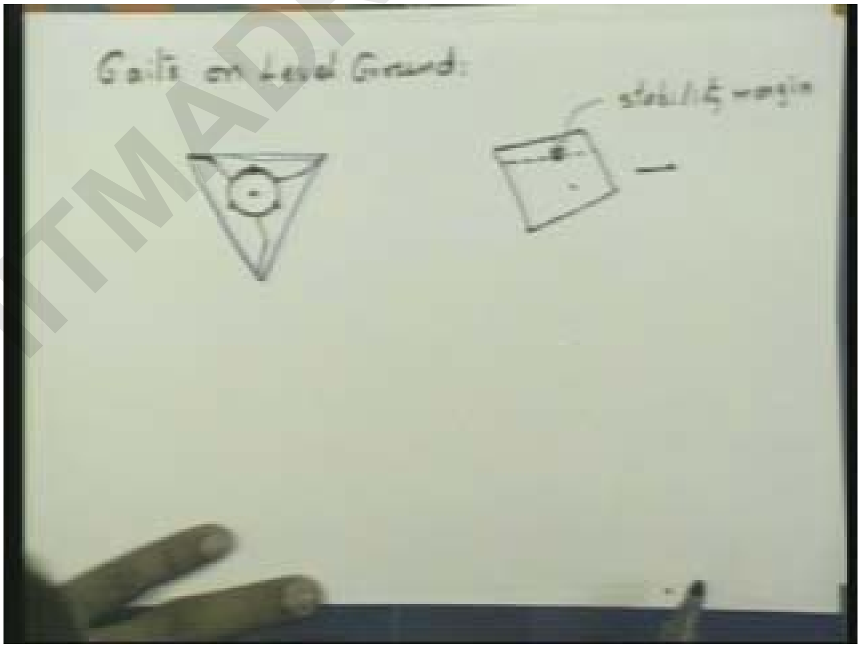

so when the machine walks we have to ensure that at every point of time there is enough stability margin okay so the two simple gaits that are used are the following these three legs are placed on the ground at the time the body gets propelled on those legs the three legs are being brought forward and then they are placed on the ground and this is going to be lifted

so when this gets lifted so let me draw that so what happens is that on this leg the body gets propelled forward so center mass keeps moving forward the body also moves forward it may come to this point right the center mass may come to that point
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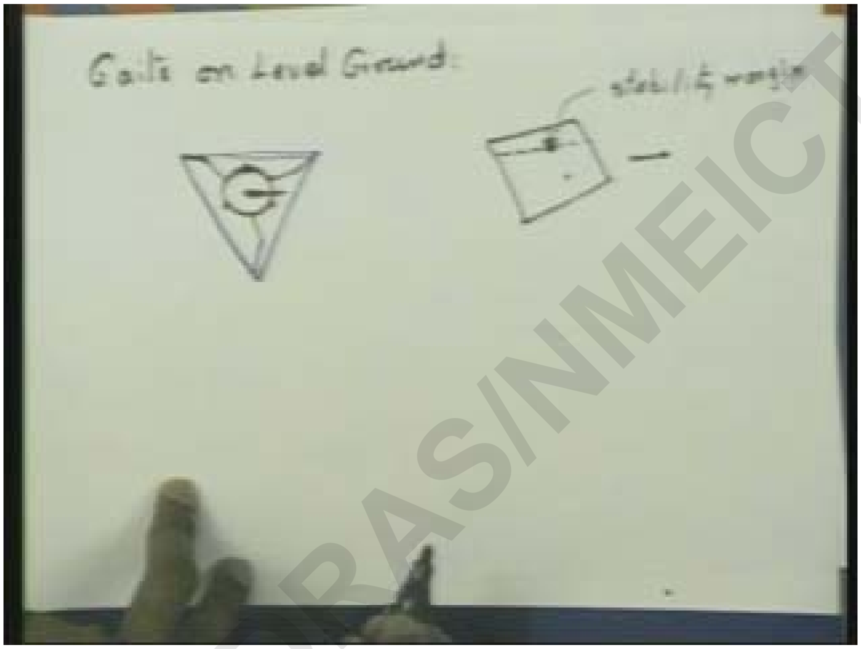
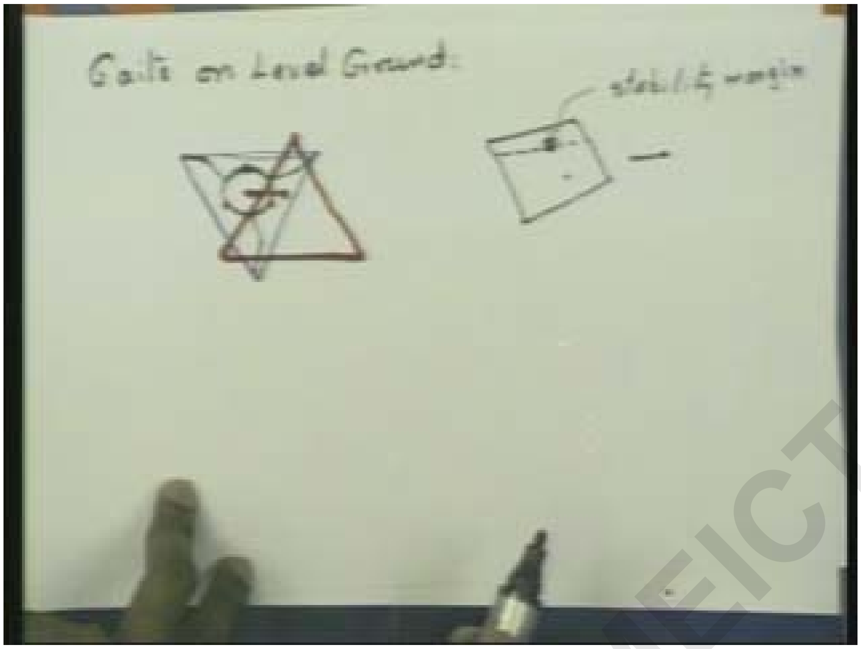


at that point what we need to do is we have to place the other tripod so this is the new position of the central mass the way we place the tripod we have to ensure that this central mass is within this tripod (refer slide time 00:12:52)



now you can lift this tripod right now on this tripod the central mass keeps moving forward further and once when it comes near the edge of that tripod you place the other tripod this is the forward progression right

three feet placed at a time on the ground and the body propel forward on those three feet this is called a very simple tripod gait and this is probably the simplest gait you can think of and remember three feet are going to be moved as if the one foot

it is almost like planting a large foot on the ground okay

now this is one of the um gaits that we consider the other gait we consider is called the crab gait that is like this its different only in the arrangement of the legs

so we are moving in this direction so there is a leg here and that may be placed on the ground lets say here the four other legs are these

then this is on the ground at this point of time and this is also on the ground at this point of time

so the triangle formed is this what is the advantage

the advantage is that following this leg is moved forward like this and these two actually backward like this

this is aligned in this direction and these two are aligned in this direction similarly the other three are also aligned in the direction in which the machine moves

at this point of time it is lifted in the air and it is being brought forward
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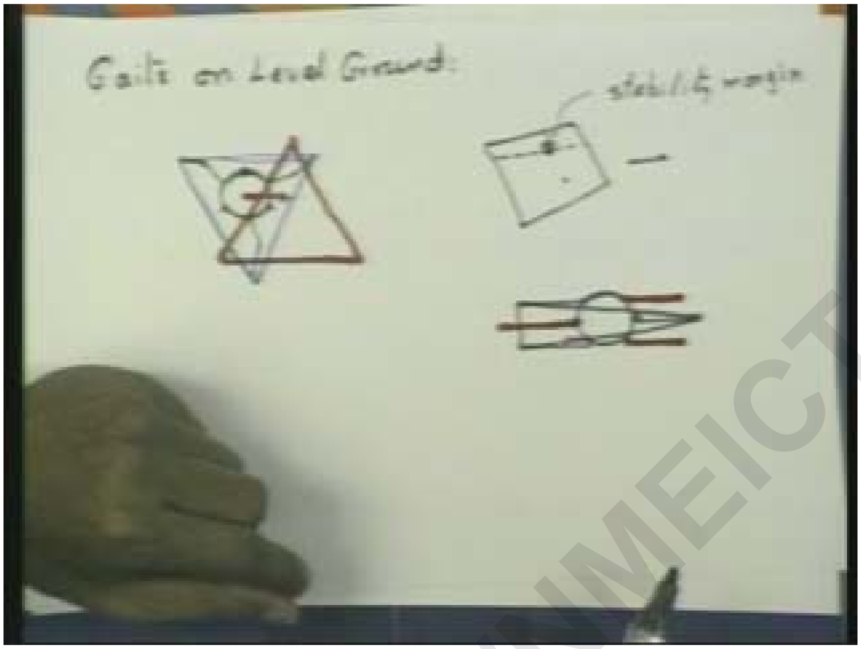
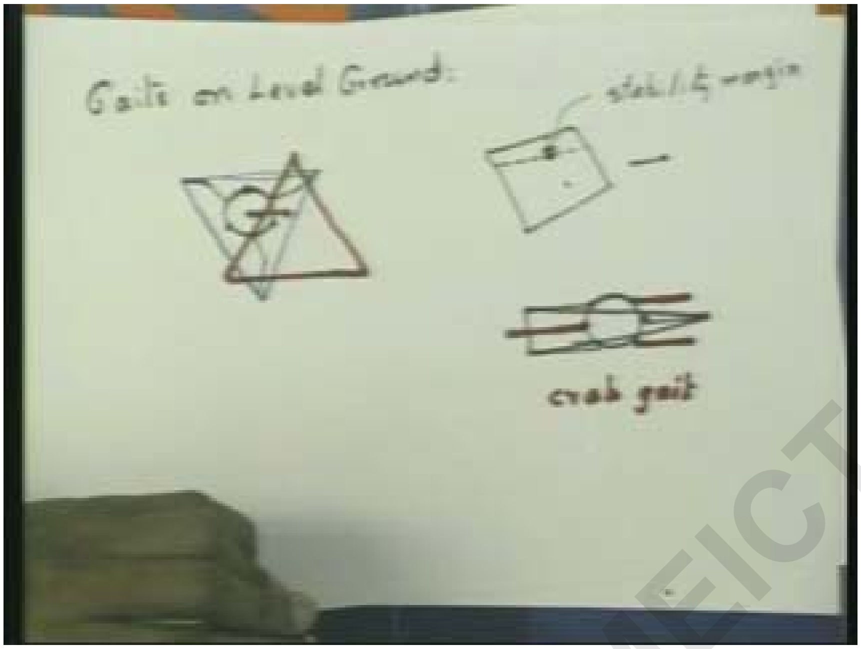


the the black triangle or the black legs are on the ground right the orientation of the triangle is different in these two cases also you can immediately see that the way i have drawn the size of the machine the stability margin is likely to be smaller here fine

so this is the other tripod gait this also is a tripod gait fine only the direction in which it is moving is along the along the direction of a of a leg and three legs are directed in one direction three legs in the opposite direction

this is called crab gait (refer slide time 00:15:37)



This roughly [the craps] both these are tripod gaits okay so in both for both these gaits i have to ensure two things sufficient stability margin and sufficient stroke for the fourth and what is the stroke

to understand what is the stroke is imagine when you walk how the foot moves with respect to you it has to be a close curve what is the shape of that curve
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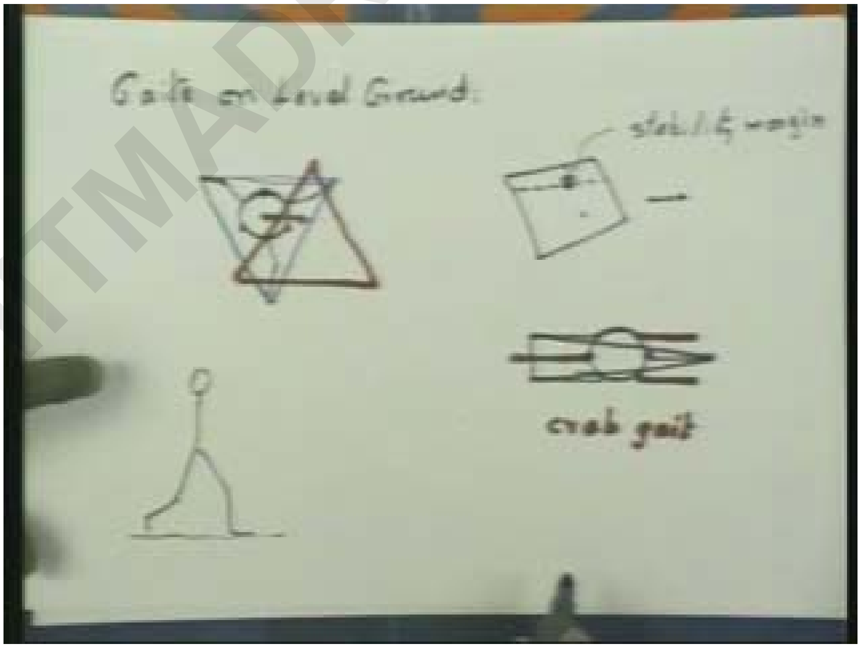
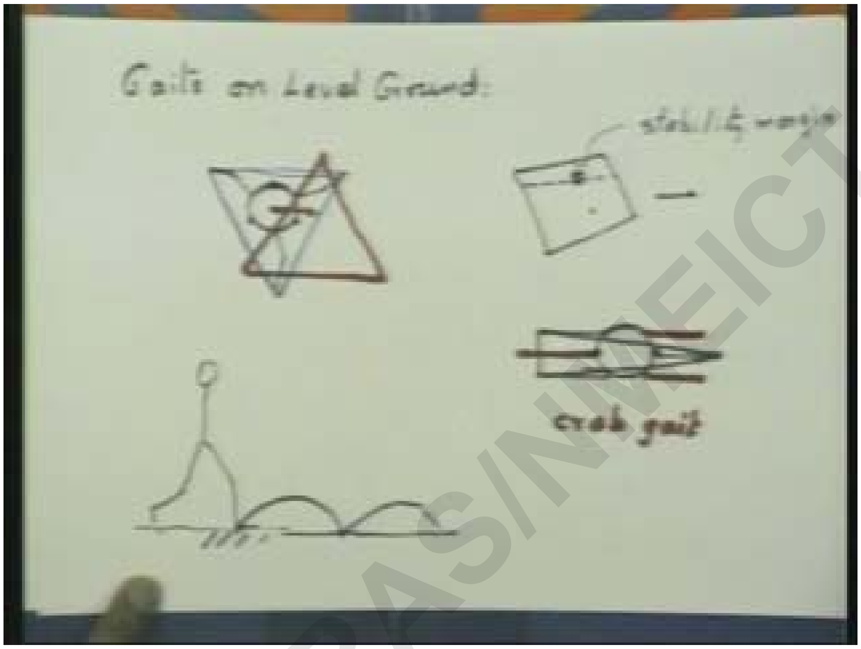


So when you walk if you look at how the foot is placed you take lets see the angle the way that moves with respect to the person is um with respect to the ground is this on the ground now and when the body moves forward it remains on the ground

At the time it gets lifted it gets shifted from here to a new position same distance as this and then in the next slide its gets shifted to this and then planted while it is here the body is moving forward remember (refer slide time 00:17:01)



this is how the foot moves with respect to the ground when a person walks but what is important is how does the foot move with respect to the person himself

if you look at that imagine that the body is stationary and the foot is moving the foot moves along a curve like this in the opposite direction of course

if the body is moving forward the foot moves in this direction with respect to the body

the stance phase that is the phase of the foot when it is on the ground starts at this point when it touches the ground and it gets lifted at this particular point right
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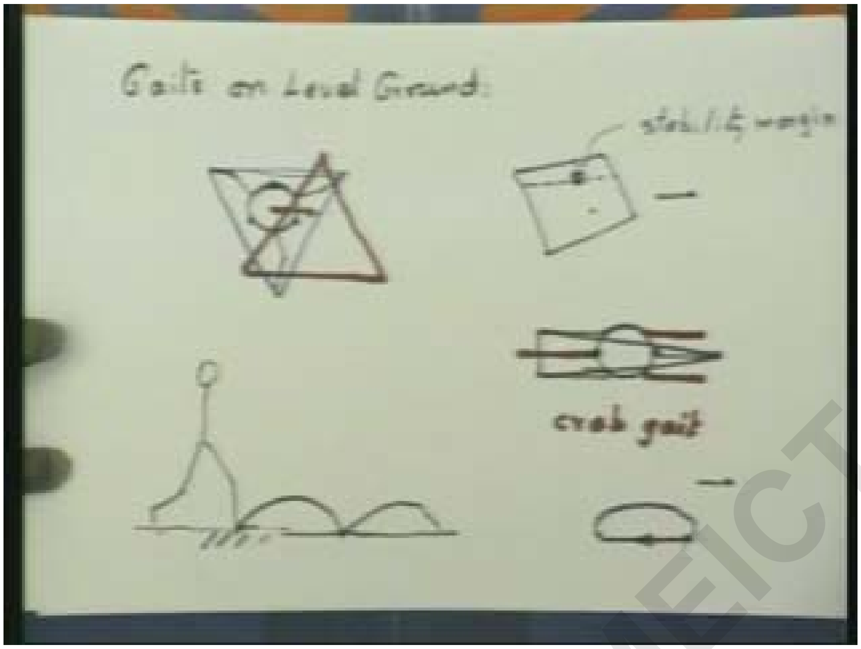
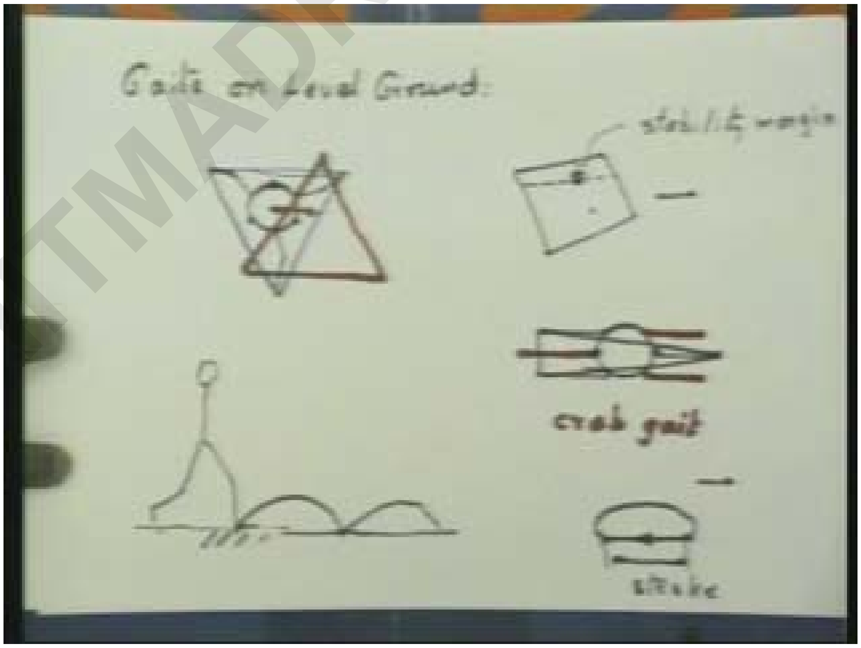


so this roughly d shape shape curve is how the foot moves with respect to the body of the machine like this also

see if we make the foot like this in an appropriate coordinated fashion we are able to propel the body forward

now the stroke of the foot is this fine (refer slide time 00:18:14)



Now we need to accommodate this entire region within the workspace right it cannot go outside the workspace of the foot so if we have a stroke of zero point five meters with some extra allowance allowed for this accelerating the foot backwards so that when it touches the ground there is no slip between the foot and the ground and for proper lifting without slip is this extra distance is required

so if you estimate some small value for that we can now design the workspace in such a way that a stroke of a zero point five meter is accommodated within and sub stin stability margin is available

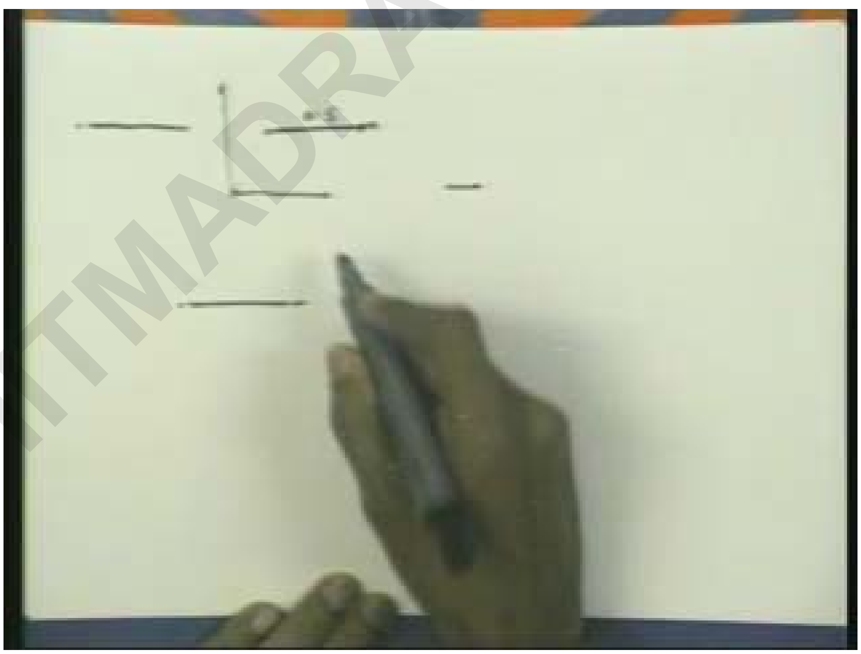
so this is the problem which has to be solved in order to size the workspace right so if you look at this gait we can do the sizing as follows

so this is the center of the um machine lets assume when the foot is on the ground it moves along a straight line like this the machine is moving in this direction so there is one foot this is another foot and this is the third fine

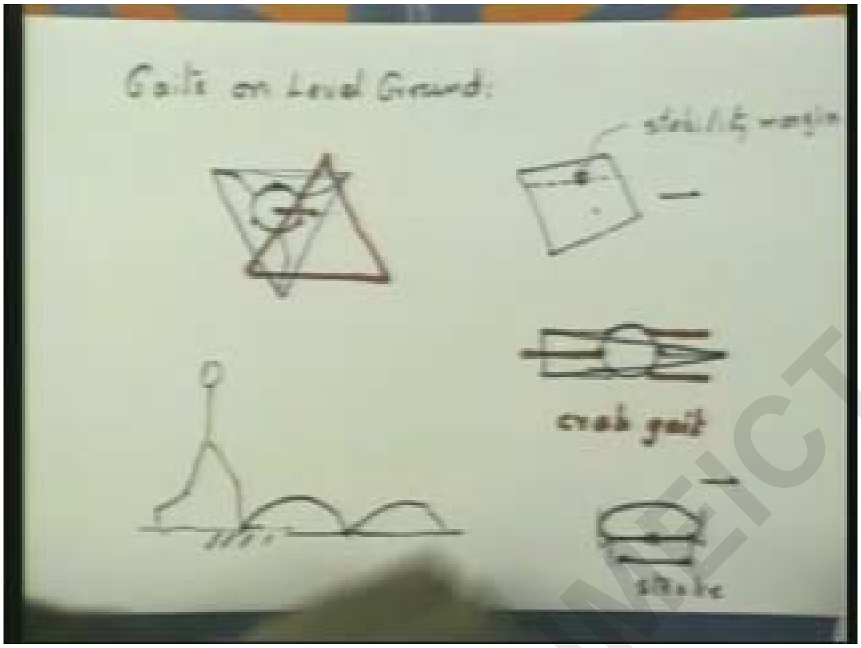
if you decide when to place the foot where to place the foot with respect to the a reference plane on the body that is during the sansquize then it is moved backwards by zero point five meters

but it has to accommodate the slight distance in front and behind all this has to be within the workspace

similarly here also and similarly here also

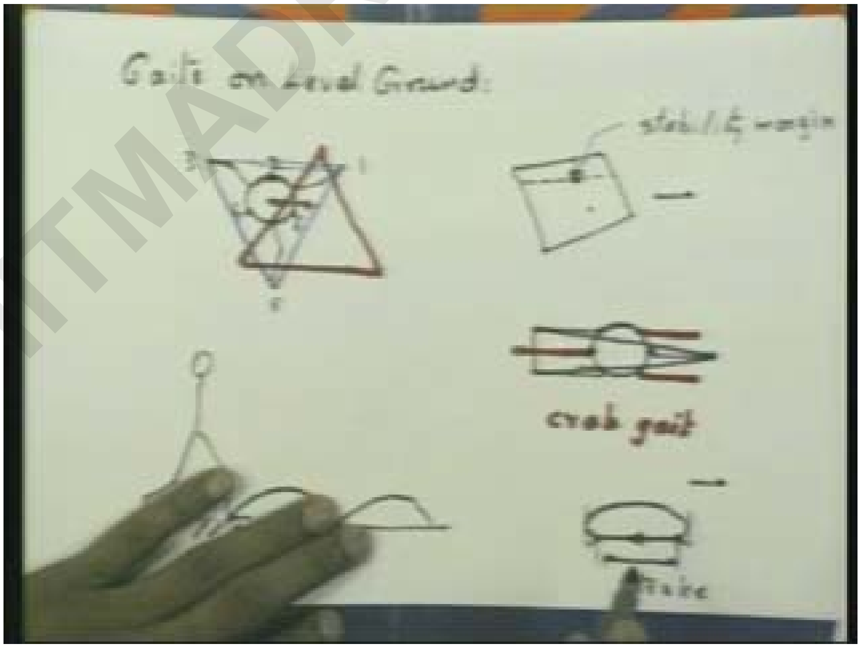


so then what we could do is we can position this zero point five meter workspace i mean stroke or the additional the extended one in such a way that it is within a sector the way we want right it has to be within so if you look at this particular type of gait (refer slide time 00:20:23)



if you look at this gait there is one foot here one foot here i mean one leg pivoted here one leg pivoted here one here one here and two here

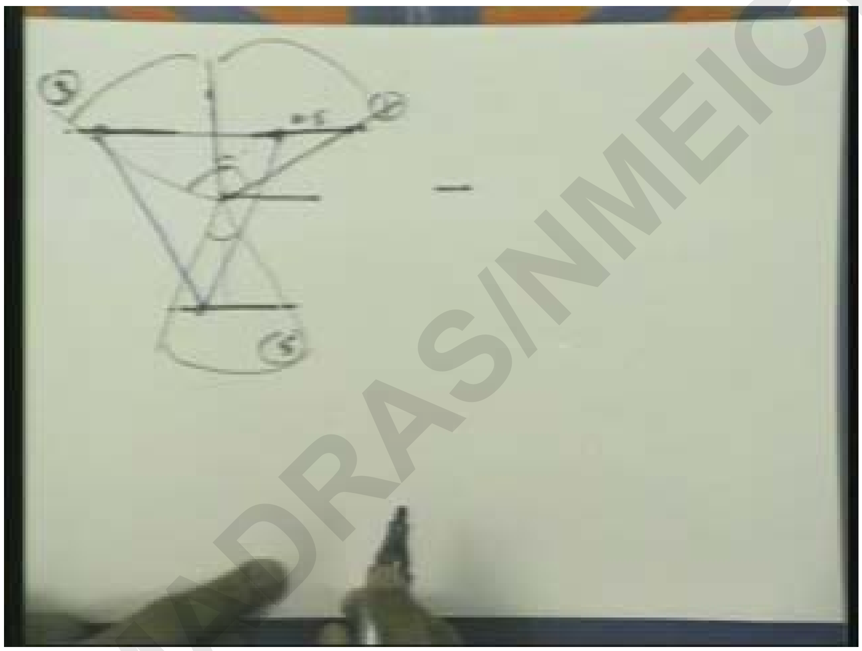
so if i number the leg say starting from one this is two this three four five and six (refer slide time 00:20:49)



if i do that the legs i am talking about here are the alternate ones one three and five then now the sector of my workspace will be a sixty degree triangle sixty degree cone i draw from here this should include this particular thing right similarly and here

so these regions are essentially the the workspaces so what i can do is i can now try to find out the smallest size of this three such that of course they have to have exactly the same size such that all this is accommodated within and in addition to that i have to ensure the following

suppose at any point of time the foot is at a particular position lets consider this particular position the foot is here correspondingly the foot here is that distance same distance from its end the foot here is at same distance from this end (refer slide time 00:22:09)



now if you draw a triangle the you would have assumed some stability margin as certain length for the stability margin

if you draw a circle with the radius equal to that stability margin that should be within this line

at every point when the foot is on the ground this has to be ensured so once we demand this and then minimize the total size of the workspace we get the solution for accommodating zero point five meter stroke within this with this smaller size for the workspace

this is a problem which can be formulated as an optimization problem and solved fine this is how we get the smallest workspace

is the procedure clear you could probably formulate it in different ways and solve it actually in formulating it um some symmetries which are obvious here help us formulate it in a more economical fashion

now this is one problem the other problem to be formulated is the same thing when it is walking with the other gait where here the inner and outer radius of the workspace can be calculated

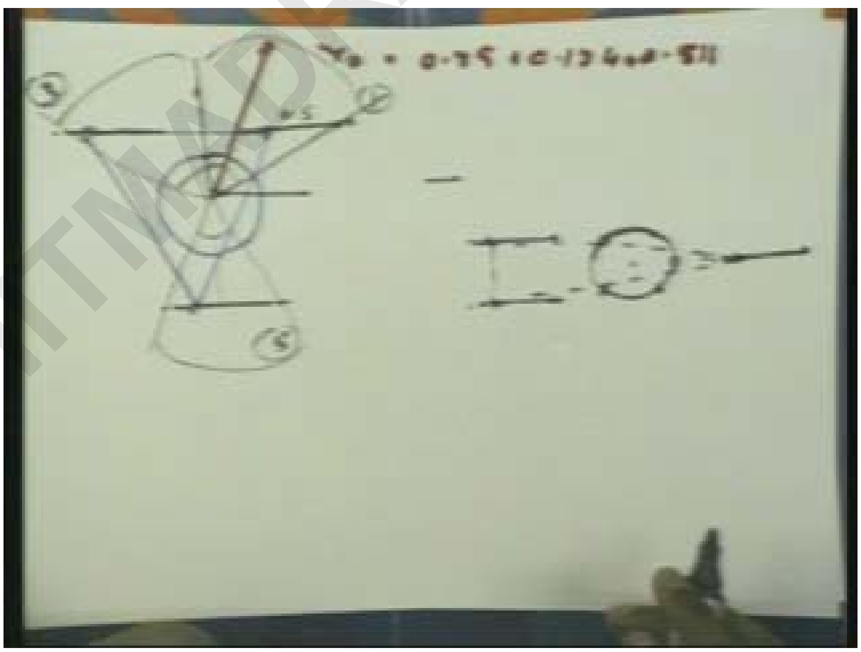
whereas in order to calculate the swell um the axis of the rotation of the leg we need to find out the radius of the body itself fine

so if you look at the gait you will remember that this gait is something like this this particular stroke has to be accommodated here so some stroke has to be accommodated here

so at any any point if the foot is here lets say then we can draw this triangle which is the convex hull of the workspace convex hull of the foot pattern and then we need to ensure that here remember the leg is aligned in this direction aligned in this direction and in this direction

so we already know the inner and outer from here fine for example the solution to this turns out to that the total [wo] the outer radius of the workspace r o turned out to be of the value was zero point two five plus zero point one two four plus zero point five one one

this was the solution for the problem that we solve fine (refer slide time 00:24:35)



there was some modifications made later so this was the outer radius this turned out to be the outer radius okay this is the distance at which the radius of the axis was initially located that actually all comes from this solution also

so let me complete this solution so now i have to figure out for a substance stability margin here where should i locate what should be the radius of the [so] these axes from the the distance from the center as well as where should i locate this that has already been decided actually from the earlier solution

so basically we are deciding here this particular radius as the um sufficient stability margin is available for this gait

so it turned out that this particular figure zero point two five was sufficient if we are prepared to bring down the stability margin to some extent here

so here you used a stability margin of zero point one two five this is what error number its here i think we need to come down to stability margin of zero point one that is what error

i mean addition to this in deciding these workspaces and stability and um workspaces in this fashion we also considered collision between feet collision between legs

now the leg hasn't been designed at this stage but the rough idea of the arrangement of the leg was known the cross section weren't till decided

but we have to estimate that and apply it here in order to size the workspace so we assume the width of the leg section of zero point one meter ten centimeters when we calculated all these

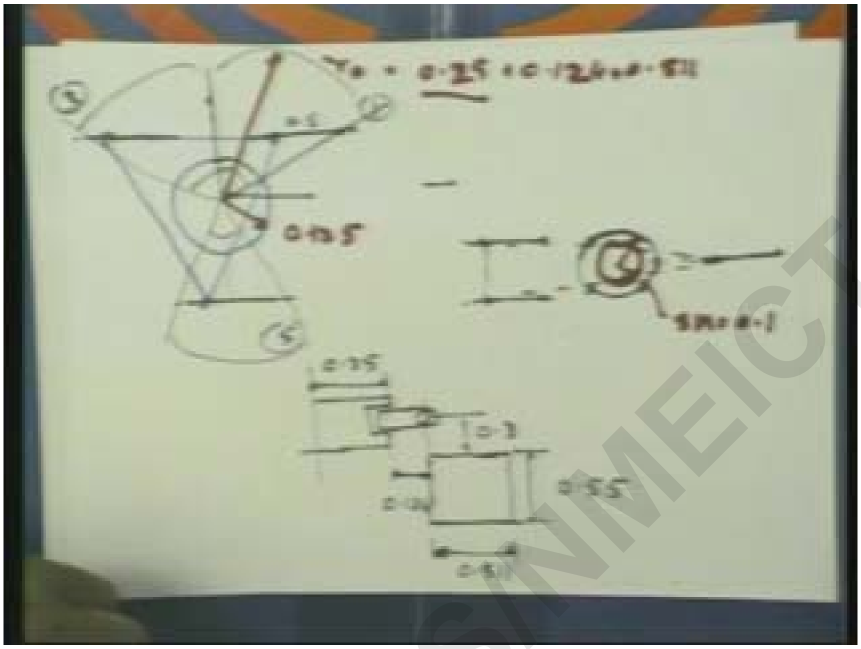
this is to check collision so all these has to be done without collision

so this is how the workspace was determined and it turned out to be the following so if i draw that let the swivel axis of the leg be this um sorry this is let this be the body and this be the swivel axis then the workspace was it turned out there an ideal size for the workspace was this

this height was zero point five five the height of the workspace which we saw this particular distance was um zero point five one one that one millimeter has now consequence

this distance in order to accommodate some hardware below turned out to be zero point three meters fine and this particular distance from the swivel axis where the workspace starts that is inner radius

this zero point one two four all these were calculated based on the considerations which i told you above the detailed formulation i am not coming to is basically a geometry problem and this is the body and the center of the swivel axis from the center of the body is zero point two five (refer slide time 00:28:24)



this was the arrangement of the workspaces and the kind of leg which will actually enable the foot to reach within this workspace is something like this

the dimension of that i will come to but the simple form of the leg is something like that

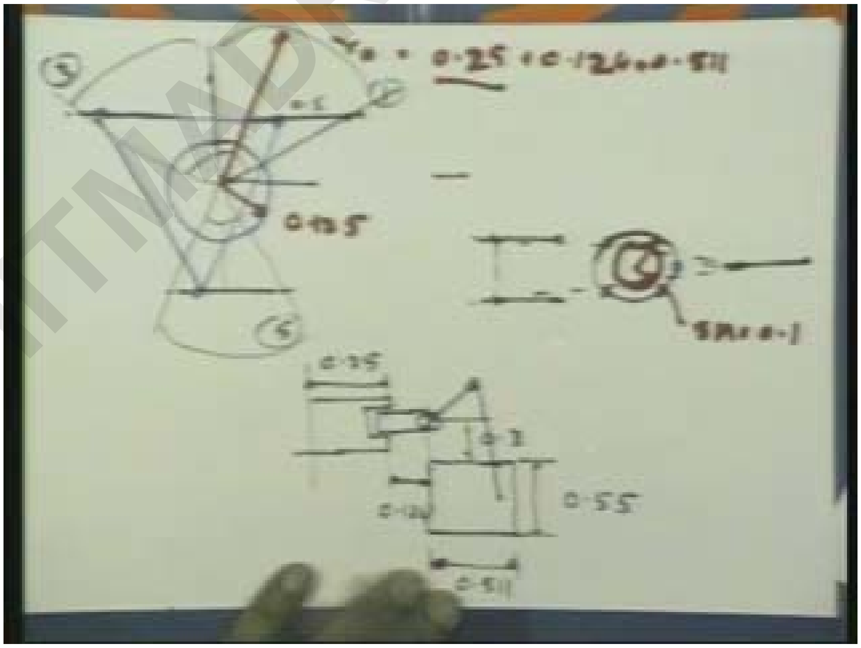
now what kind of a leg will allow us to reach this kind of a workspace the mechanism of the leg has been designed

how do we proceed with that design so it needs to access the workspace like this
(refer slide time 00:29:26)

there is one mechanism for the leg which is very very popular in walking machines there are a couple of reasons why it is popular

it is based on the pantograph i draw the pantograph and explain why it is popular

so look at the earlier figure if you look at the earlier earlier figure
(refer slide time 00:30:24)



i have drawn the leg as just a a two link mechanism right this is the leg is pivoted to this particular body which can rotate about this axis so this particular body i have drawn here (refer slide time 00:30:41)

this is what it is and the part of the leg i drew there is just this part okay

lets call this point A B C D and E and this is the foot F fine
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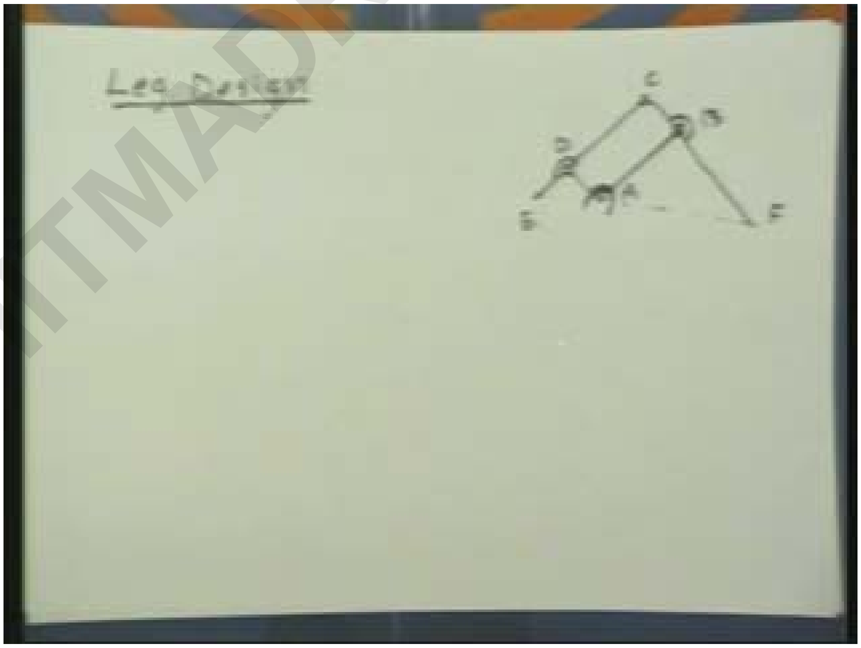
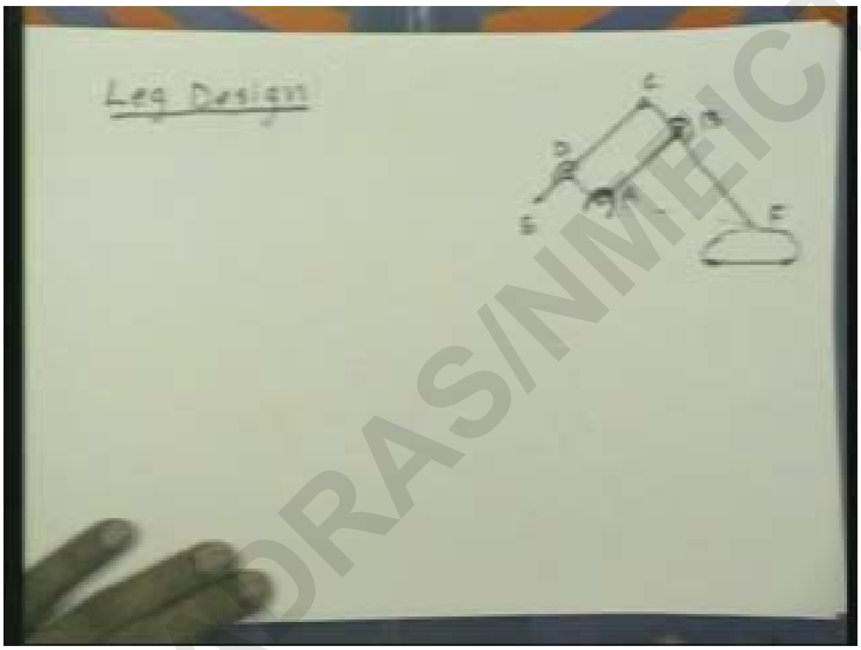


now why this is a pantograph um its special property is that if i now move this along some curve this actually moves along a scaled version of that curve may be there is a reflection also

but essentially a scale and scaled and reflected version of that curve okay the scaling factor is equal to the ratio of these two distances which is the same as the ratio of the sum of the other distances in the mechanism

now how do i move this particular point so what i need to do is i need to move this along a d shape curve right i need to move this along a d shape curve this is the stands portion correct this is what i need to do (refer slide time 00:31:47)



now this can be done in different ways you can attach a two degree of freedom mechanism to this this being the couple of point on the two degree of freedom mechanism and then this point can be moved in any fashion that you want

that’s one way you can do this fine so this has been done in different ways one way it is done is for example um make this particular move along a vertical curve vertical straight line

make this point move along a horizontal straight line so these two motions together will enable you to obtain any motion that you want here okay

now the reason why pantograph is useful is the following if you can ensure that one advantage is that the vertical motion and the horizontal motions can be decoupled can be handled by two separate actuators so when the vertical actuator vertical motion is needed you need to move only one actuator then the horizontal motion is needed you need to move only one actuator this is an advantage

this decouples this simplifies the control of the system but the other advantage is related to energy it turns out there um if we are moving them actuator is suppose the weight of the mechanism weight of the machine while it is moving forward without changing shifting the center of gravity the power the work that needs to be done in order to actually support that weight that is wasted that really is not adding to the change in energy of the machine

so it turns out that a pantograph mechanism helps you there are other mechanisms which will also help you there which help you minimize the dissipation due to this kind of energy loss

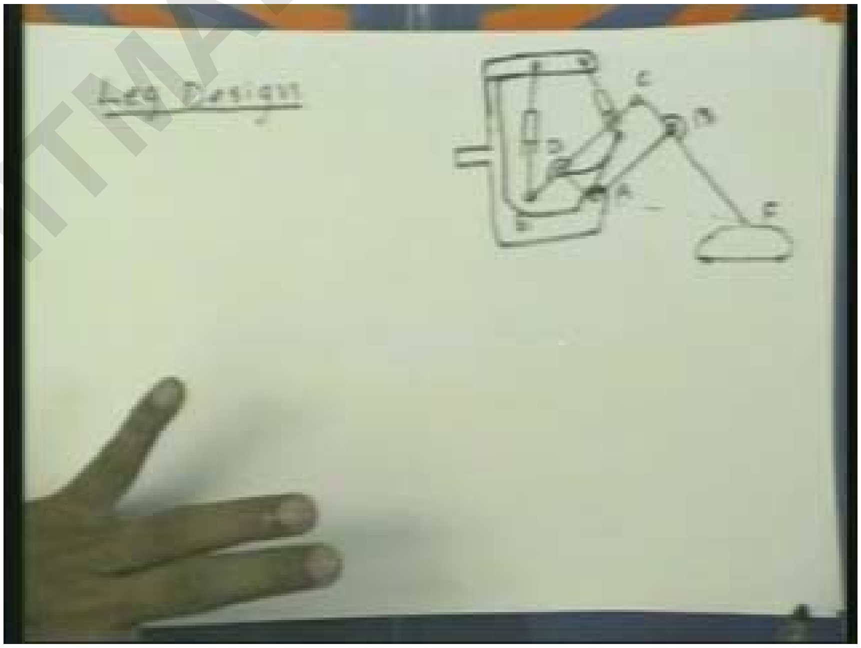
it is a concept which i don't want to go into detail but its another reason why pantograph mechanism mechanism is found to be useful [noise]

now let me show the arrangement which is used in our machine in order to move these to this point along a curve like this

slightly different from what i described what we did was we had a linear actuator here we added a link to this a part to this link and at the end of this we had another linear actuator

these linear actuators were mounted on the body which are which is to be skewed rotated about a vertical axis i should have put it on this so pardon

the arrangement was this (refer slide time 00:34:52)



this is the frame of the leg that will be rotated about an axis like this

this part of the mechanism with a foot is basically a planar mechanism which works on this mounted on this frame okay

it is a two degree of freedom mechanism moved by two linear actuators changing the length from here to here and from here to here is the way we make the mechanism move

now it turns out that if i lock this actuator and move only this actuator this moves in a roughly vertical fashion it how does that happen i will explain

when i lock this what happens is that this link is allowed so the whole thing gets converted to a one degree of freedom mechanism now

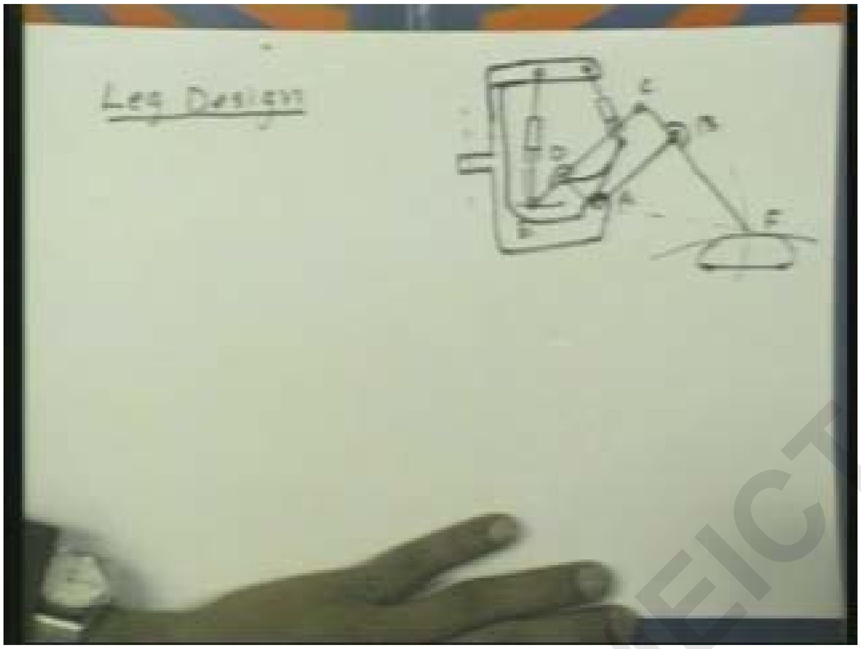
with this link locked and this particular pivot also locked in position

now when i move this actuator this point is moving along an arc with this as center an arc like this

this being a pantograph mechanism you see exactly the same arc here in this fashion so that is a rough vertical motion

what about the horizontal motion if i lock this actuator and move this i told you that this ares one degree of freedom mechanism

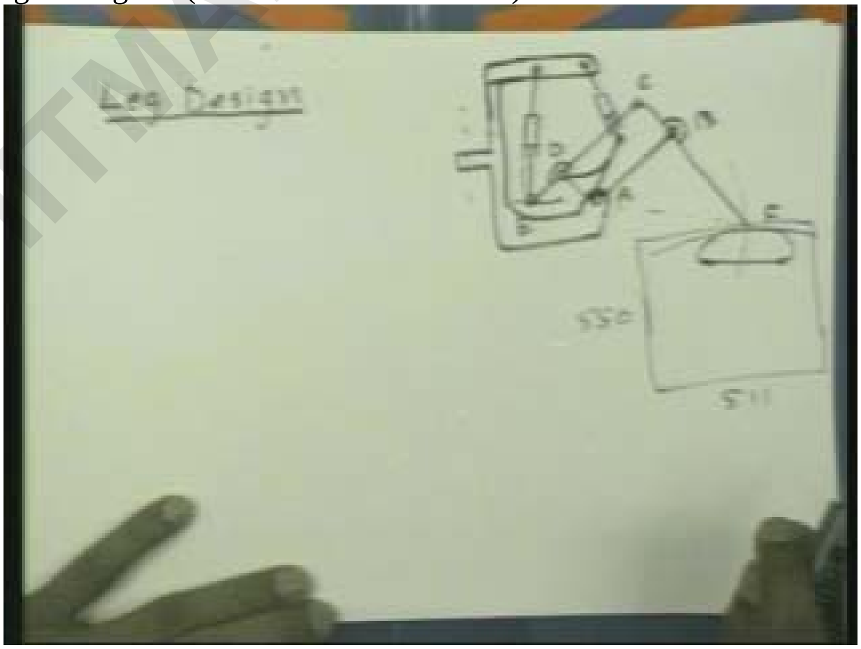
because i have locked this this length remains fixed and this is pivoted about this so obviously this point is going to move along an arc with this as center and that will be roughly horizontal and you will see that the horizontal arc being obtained
(refer slide time 00:36:42)



there is a reflection the way the mechanism makes the there is a reflection of getting the curve here and the curve here in case reflected about this

so this is essentially how you generate roughly vertical motion and roughly horizontal motion by these two actuators this is not perfect decoupling but it is decoupling to a great extent fine

so this is how the mechanism works and it is designed in such a way that this linglands are chosen in such a way that the total length is small as small as possible and it is able to access the region which i told you that five fifty millimeters by five hundred and eleven meter rectangular region (refer slide time 00:37:29)



um in addition we ensure that this particular angle which is equivalent to transmission angle in this case is not too small or too large

so this again is posed as an optimization problem and we get the linglands

in order to do this we also assume that the ratio of these two curves we took a ratio of five is to one or one is to five

this was a right roughly adhoc decision which was checked later with some other values fine this is the design of the leg okay the whole thing is put into body there are six legs like that all around

and while designing this you have to ensure the way you put the links actually finally this only a kinematic design finally you will have to embody that you will have to size the cross sections and you have to decide the bearings the type of bearings

so you need to place various links with respect to each other in this in this direction

so all that is done considering various interferences that can happen while the leg moves fine and the cross section is determined based on the various forces that are going to come on the link

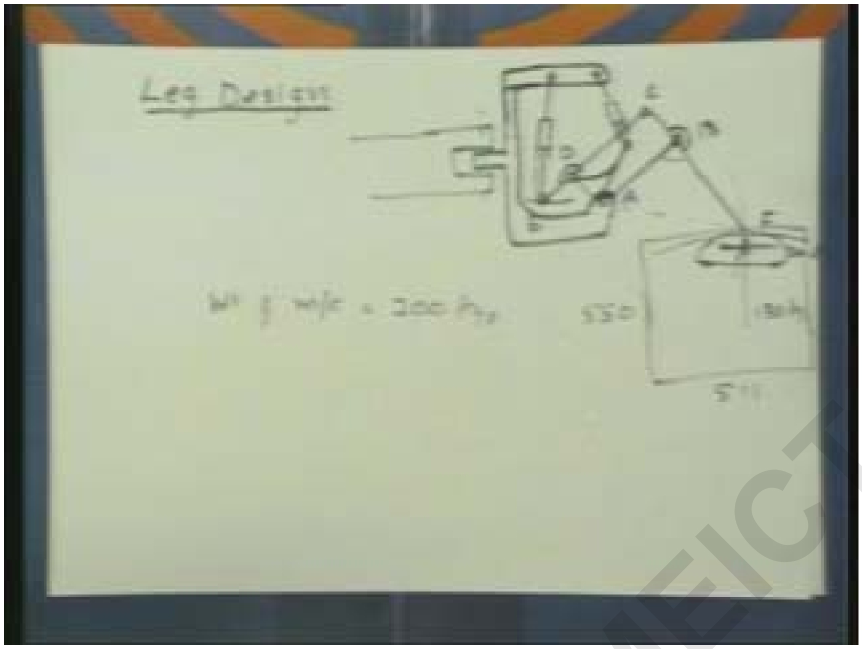
the forces are changing because we have forces at different points in the workspace okay

so one of the considerations for that is the vertical force that is going to see we had an estimate of the maximum vertical force it is going to see and that has to come from in a estimate of the weight of the body the weight of the total machine

so we cannot proceed further without estimating the weight of the total machine

now how do you estimate the weight of the total machine we arrive at some starting value so rough estimate it as two hundred kilogram first based on that we based on that triangle tripod and all that we estimated a maximum of hundred and thirty kilogram force to act vertically on a hook

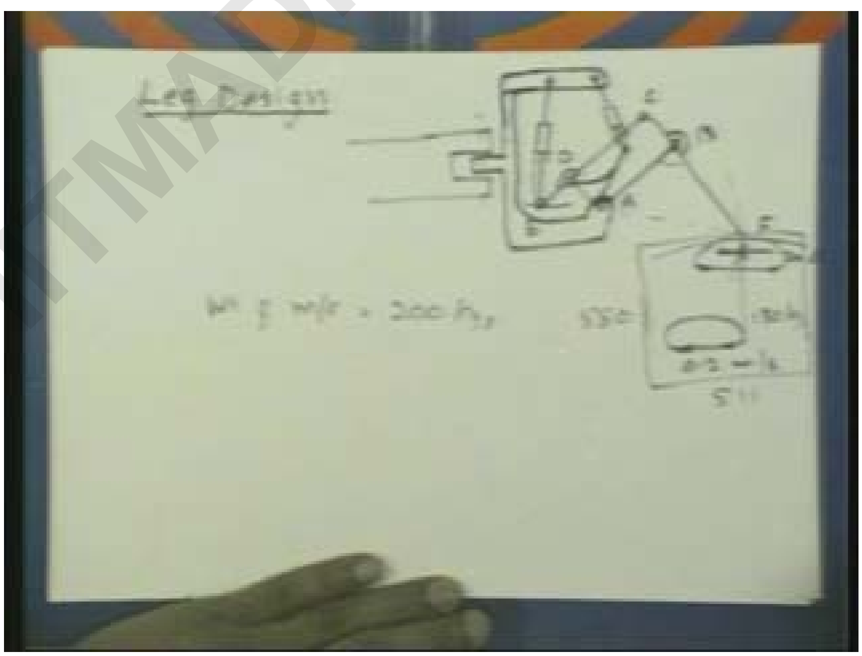
and a maximum of twenty kilogram force to act horizontally this twenty kilogram force comes from the ram which has to climb fine (refer slide time 00:39:52)



so based on all that we arrive at the forces on the various links on the field from which we can estimate the cross sections of the leg

after you get the cross sections you have to move this along this various d shape curves with certain velocities

we had estimated a certain velocity for moving forward it is zero point two meters per second (refer slide time 00:40:22)



so you need to have some acceleration deceleration because this been lifted and brought down as well as brought forward and back

so based on all that we can estimate the motor sizes motors can be selected based on that once you select the motors you start getting on idea of what is the real weight of the whole thing not only the motor but actually the gear boxes also

then we need to check whether our two hundred kilogram force was sufficiently accurate

our initial estimate was that it is all right we can proceed further but it finally when it was finally fabricated it turned out there

some of our initial design were faulty because the cen was not sufficient it finally turned out to be closer to two seventy kilograms force

luckily the models that we had selected that was sufficient and the leg design was with some leeve so it can actually support two hundred kilogram force not one thirty kilogram force

so it was able to accommodate this increscent gait only the motors are not able to give us the point two meters per second that the initial one

so some compromise had to be done fine

what am i trying to say is that a design like this cannot actually take place in a very sequential linear fashion

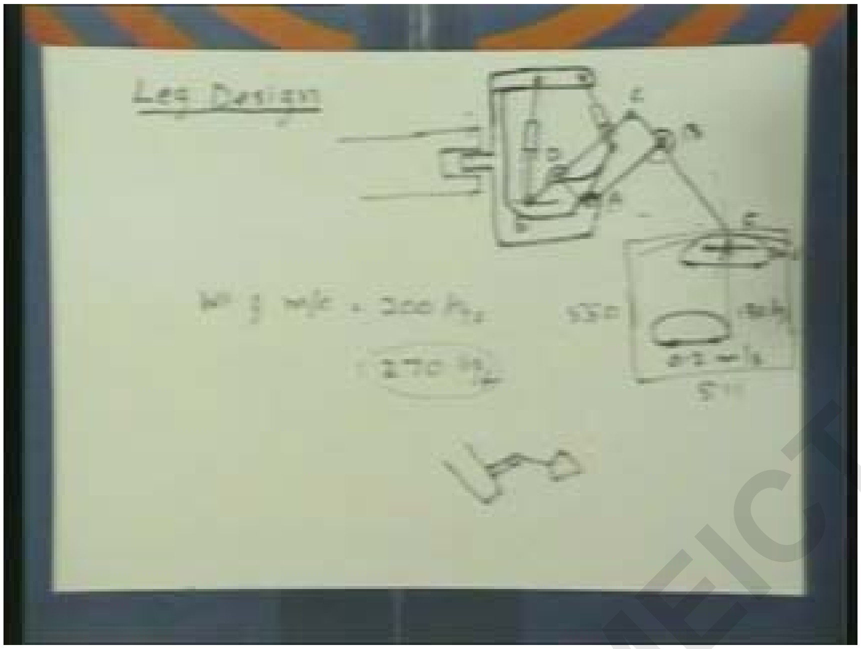
it is an activity which requires some quite a bit of act iterations you have to use certain in builts which are um which at the beginning you can only estimate you don't know exactly you have to make those estimates proceed with the design

and once you proceed with the details of the design you start getting more accurate values of those inputs so thats the estimate

then you have to iterate you see whether all aspects of the design which we designed it for are satisfied with that the values fine

so this is with regard to the and this is some of the important aspects of the design of the walking machine like this.

and if you look at this you will see that this is almost a three degree of freedom manipulator if we put the wrist on the end of it you have a regular manipulator right and what we were proposing was add a gripper so add a couple of mouldings with a gripper so that it will be able to do some symbol maintenance operations okay (refer slide time 00:42:53)



so now i don't want to describe the design aspects in it further because there are a lot of details which i can get into but we don't have time for that

so i want to spend um the next ten minutes describing how we would control a machine like this (refer slide time 00:43:38)

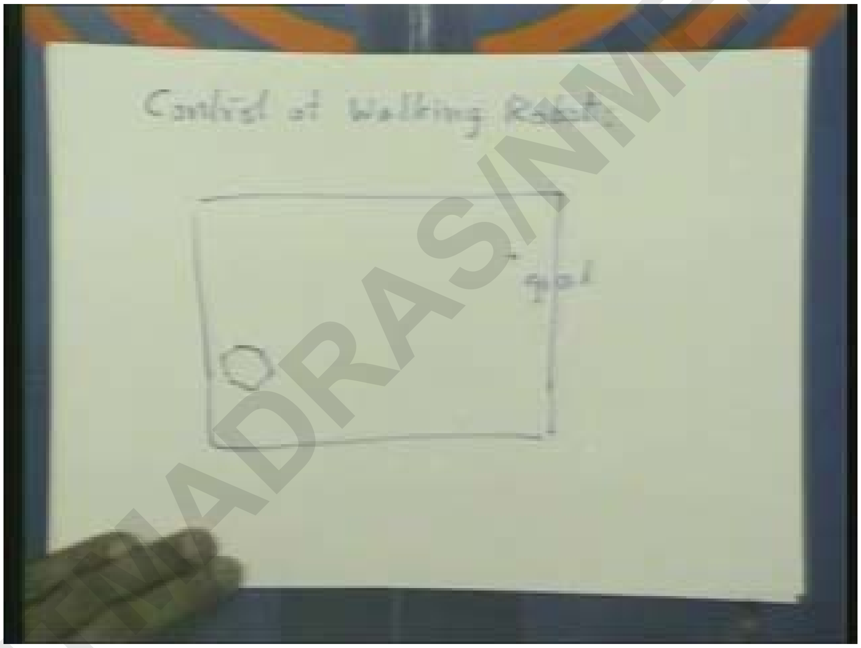
let us look at typically how the operator would like to interact with the machine and give it comments so as an operator what would you like to tell the machine there is a machine which can walk which can move its body from one point to another in a environment right

so how do you like to what is the easiest way you would like to give comments i would like to simply specify a new location to which it should go as simple as that right

if i have a pet dog i will say go there right [noise] and i will point like that i should be able to specify a location in a room which it will be able to recognize and it should be able to do the rest it should be able to walk to that position

now that position may be at a higher level right so let me pose that problem the machine is at some position the operator sitting at a console and its in a room i should be able to simply say this is the goal and give it to the robot the robot should be able to go there

at this point of time the robot may be somewhere here fine (refer slide time 00:44:58)



should be able to somehow go there now look at what the robot has to figure out in order to reach there

i showed you the room in which this has to be there so there may be some table out here right there may be some pipe laid on the ground like this there may be another table out here

now how does the robot figure out the figure out how to reach this space wherever the robot is one essential thing is that it should know where the goal position is

you should also know whether it is at the level at which it is or it is whether it is on a another um another level in the vertical direction right if it is on the messanine floor then it has to climb some steps to go there it cannot be a point out in the air right that is hanging in the air whether robot cannot reach

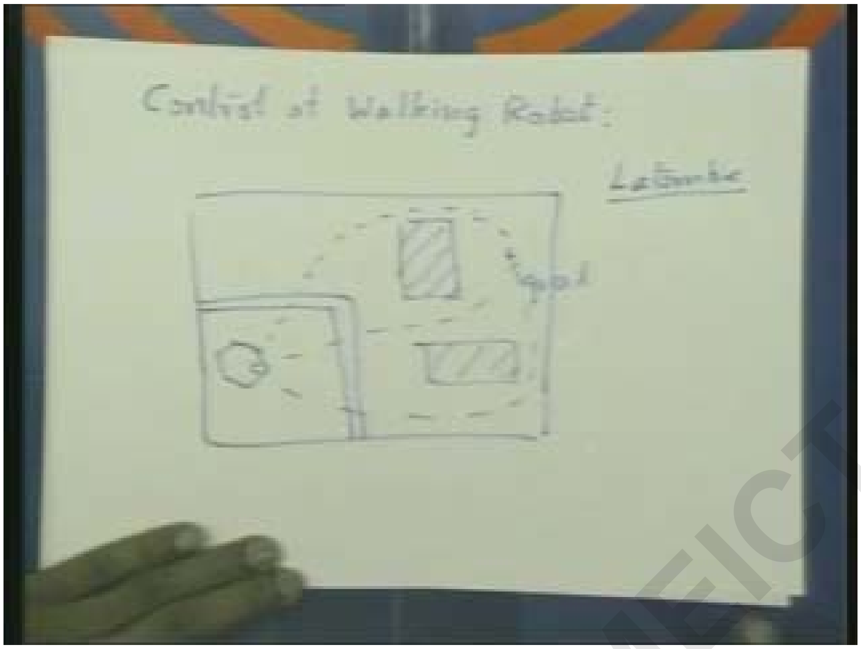
so now it has to figure out a route to reach there the route could be has to avoid this obstacles has to step over these smaller obstacles it can be like this it could be like this it could be like this there is to figure out a route right (refer slide time 00:46:27)

and in finding out the route it has to actually avoid the obstacles a route is one which is a free floor right a free space it can move along

so it has to first figure this out and after after figuring this out it has to move along that right so the the the problem of figuring out this particular route or a path is called path planning right

i have briefly described that at some stage i have um that is called path plann right

it is a usually tackled as a commenatorial optimization problem using graph search fine you can look up the book by latombe (refer slide time 00:47:23) in order to have a understanding of that



having figure figured out a route lets assume simplify the problem and say that there are no more obstacles and simply a path from here to this point so start goal
(refer slide time 00:47:44)

so what i mean is that the entire path the central mass of the mou of the body or the center of the body has to trace while it walks on here to here is decided fine

it is actually detrimental to decide it excitedly initially because while its moving here something may come across you may walk across robot may have to stop allow you to pass and then move forward or it may be it may be that in figuring out the route you hadn't used any detailed information

and this may turn out to be pretty close to some corner and you may have to take some deviation fine

so all this may have to be done but for the moment lets assume that this part is exactly given and your job the machine's job is to make it send of send a move to this part okay

so while doing it lets also assume that at any point you suppose that robot has only two cameras and it cannot be shifted too much the cameras cannot be reoriented

then while it is walking it would like to see the place where it is going to step its going to go forward it t would like to see that

so at any point of time the robot would like to orient itself in such a way that it is looking ahead correct that is ideal when we walk we don't walk sideways unless we look at that side we would like to see where we are going

so this is one way the robot can go but if it has cameras all around this is not a big problem at any point it can have any orientation

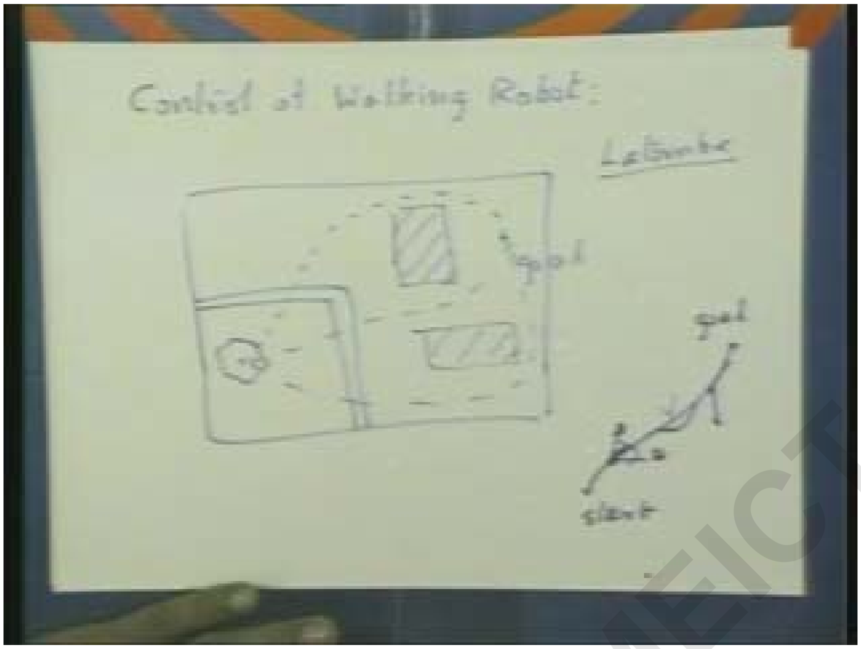
so while it is moving along this part the orientation itself may be specified in a arbitrary fashion fine

so the entire motion of the body except for lets assume that while the body is moving its it is kept vertical the body is kept vertical it doesn't tilt with respect to gravity

there is an advantage to that our design the advantage is that the fuel actuators don't start feeling too much torque it will get tilted itself feeling torque

and the fuel actuators are not all that powerful cannot apply too much torque so it may not be able to actually sustain that kind of problem which will come on it when the body gets tilted that is why we don't want the body to be tilted

the body is kept vertical so then only three parameters define the position of the robot one is this particular angle it makes with some global reference plane theta the other is the possession itself of the central mass of the robot in some global reference
(refer slide time 00:50:26)



it is like planar motion right so the palnar motion of the body is entirely specified once we specify the path and the orientation of the machine

now we may need to make the robot move along that the two gaits which i have have shown you are gaits which will take it along straight paths without rotating

we need to figure out gaits which will allow it to move along curve paths as well as rotate itself

this particular problem is called gait generation once you generate the gait you get the information about how excitedly the foot has to be moved with respect to the body the motion of the feet with respect to the body

at the end of gait generation you have that particular calculation particular information then what needs to be done is the following

once you know how the feet has to be moved with respect to the body it is the problem of tracking which professor Gandhi described in in the control course

you need the end effect to move in a particular fashion as the function of time you need to move the motors in order to move the end effect like that and if there are disturbances while it moves you need to correct and still move along high as close as possible along the path which was specified

so it becomes the problem of tracking a given motion of the end of the foot um end of the leg that is the foot with respect to the body of the machine this actually is a fairly complex mechanism with a lot of nonlinearities in order to do this when doing this

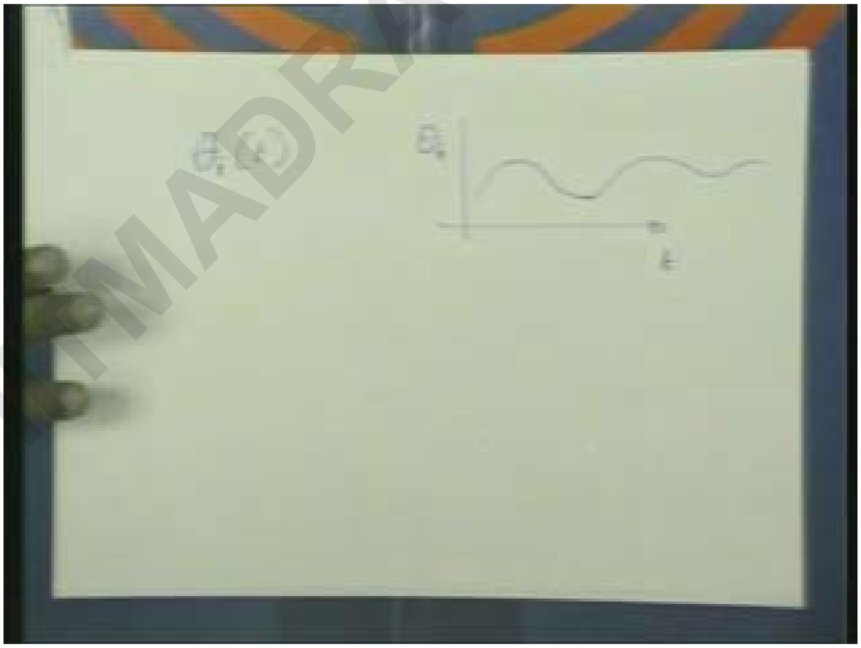
but if you do the inverse kinematic calculation which um i had described earlier if you are given the possession of the feet in the body contact train at any point of time you will be able to calculate the length of this actuator at any point of time in order to take it through this various possessions and also the angle made by the swivel actuator at any point of time

so basically you would be and these particular linear actuators also the length is changing what is that really happening is that their motor is rotating rotating a lead screw and the nut is moving along the lead screw in order to change the length of the actuator right

so the length of the actuator can be linearly um is linearly related to the motion of the motor

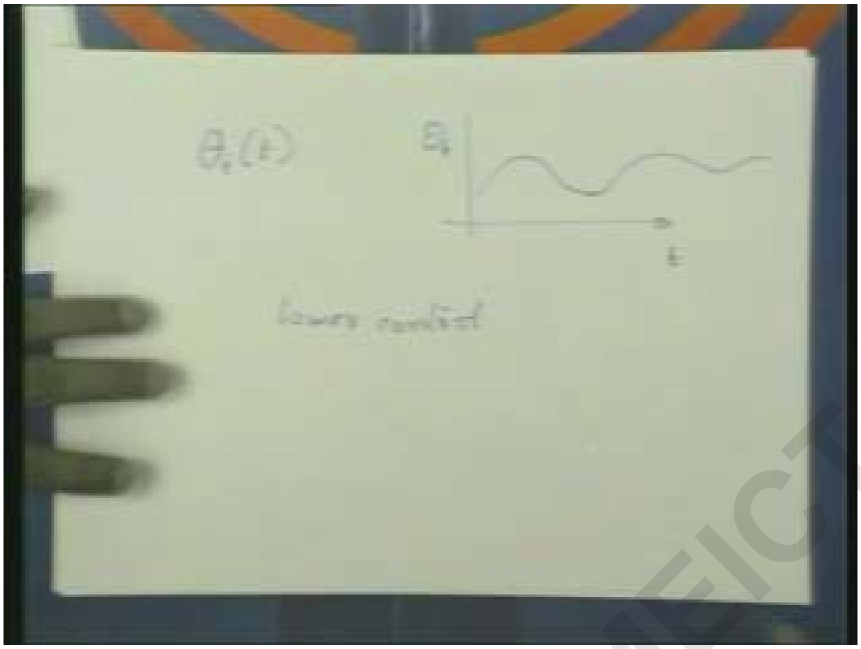
so finally what you need to control is the motion of the motor so you basically have the information about how how the feet have to be moved with respect to the body is converted to how the motors have to be moved as functions of time

this may be some motions like this and what you need to then do is make the motor move excitedly (refer slide time 00:53:30) like this that is the shaft angle change with time in this fashion



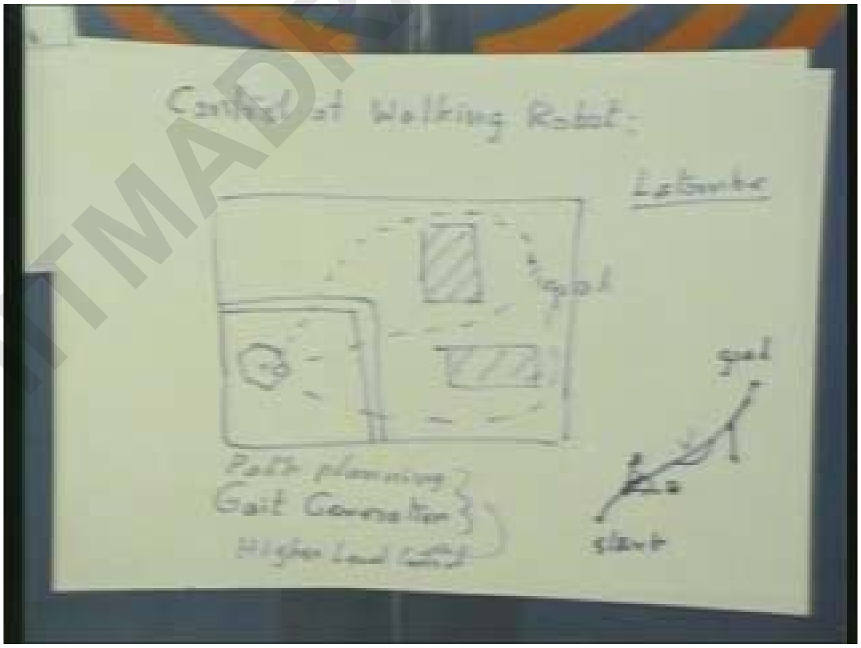
and this is done by feedback control using encoders of potentiometers which are measuring the motion of the leg fine this is how the final control is

this part of the control is called lower level control (refer slide time 00:54:02) fine



and this part of the control gait generation and path planning are sub problems under what is called higher level control

this division of the total control problem (refer slide time 00:54:27) into higher and lower level so different levels is actually to make the break the problem into sub problems which are easier to solve



if the problem is given as i want to go from here to here now find how to control the motors in order to do that it is actually a very large problem it is broken up into these segments in order to actually solve each of those sub problems in a simpler fashion

each of those sub problems turn out to be simpler than the larger problem and it is easier to solve okay so in almost any robot you will have the higher levels of control where the which the purpose of that is to convert the demands or the commands of the operator to the motions of the body the reference motions of the body

and then the lowest level which takes the reference motions of the motor and tries to achieve that um fine this is too in a manipulator also

so the problem of trajectory planning or joint interpolation and all those things come under higher level

the problem of the manipulator control using the dynamics and all that which professor Gandhi described comes under lower level

lower and higher doesn't have anything to do with the complexity of the task fine it simply has to do with the position in the hierarchy into which the total problem is divided okay

so this to fully describe this particular case study quite a few lectures are required so in this two lectures which we had this gives you a flavor of the total problem and some of the segments of the problem okay