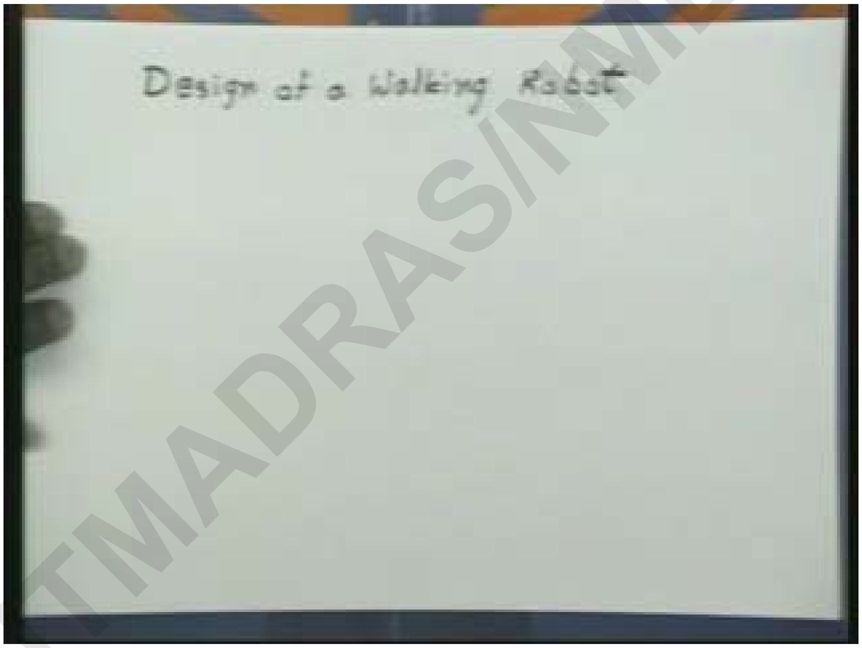
ROBOTICS
Prof. K.Isaac
Department of Mechanical Engineering
IIT Bombay
Lecture No-38

Um what we have been covering so far are um mainly industrial manipulators or industrial robots which are stationary we um discuss the the various sub systems which um they are composed of the hard that is the hardware which goes into that and also um which are the major calculations to be done by the controller and um at the higher level um and how does one control it at the lowest level that is automatic control with feedback

we also saw one um sensor which is at higher level which is used at the higher level that is the camera um so what will be discussing today and in the next class is a design of a walking robot which we have done in robotics lab so we can give you the details of the design (refer slide time 00:02:29)



now walking robots um come under the category called mobile robots

mobile robots are obviously different from stationary robots

stationary robots have their base fixed um to the global reference plane whereas mobile robots can move its base is not fixed it can move around

there are various applications for which mobile robots are used I list a few of them

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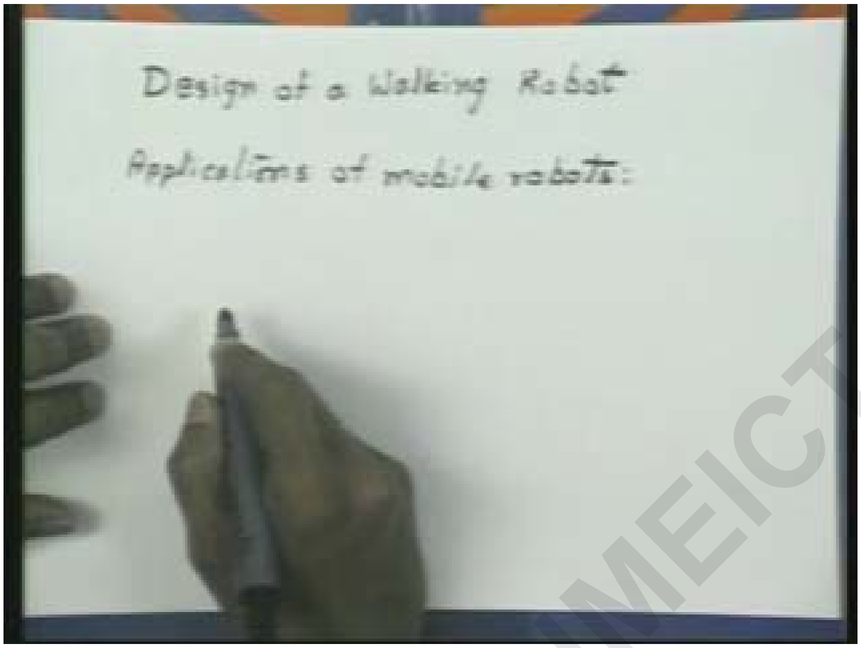

i will give a set of typical applications say material transport in factories
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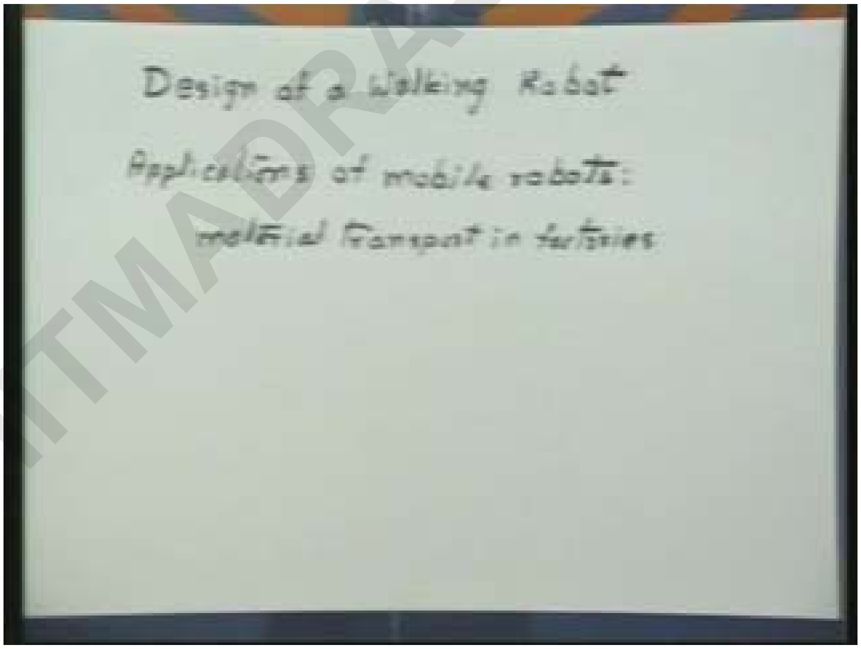
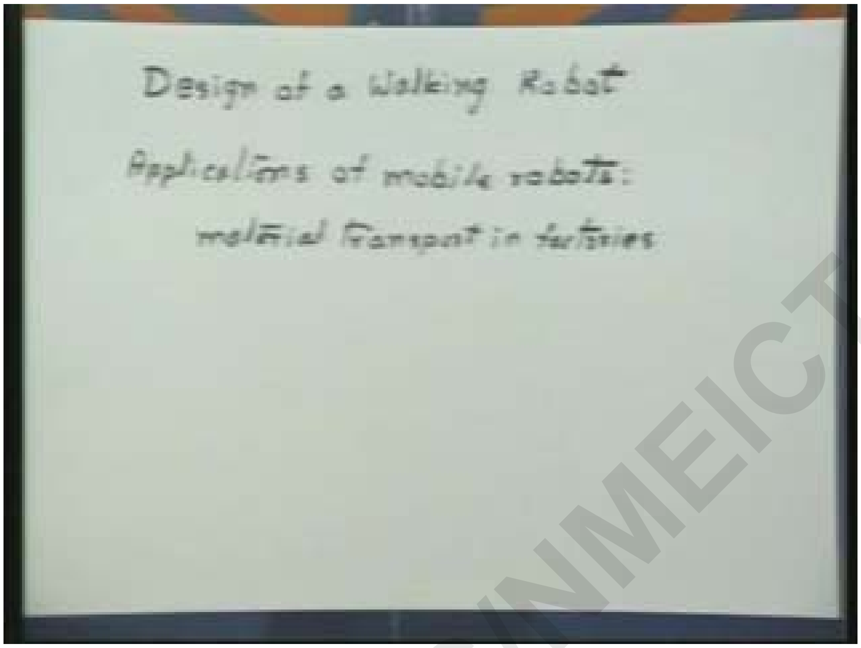


what are typically used for material transport in factories



you have overhead traveling cranes right cranes are used to if you want to carry something slightly heavy um one possibility is to use mobile robots for parts which are not very heavy

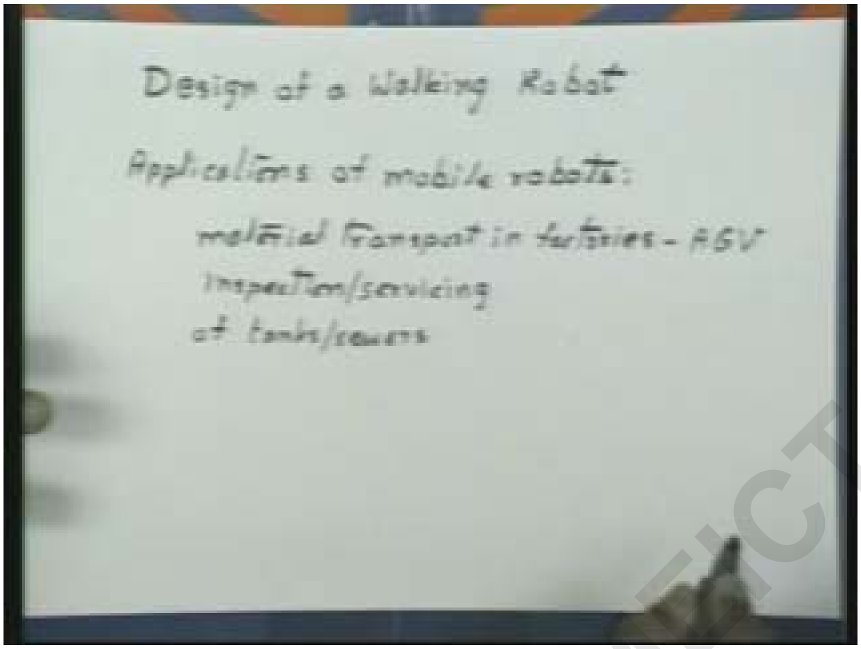
so a typical example is the automated guided vehicle AGV stands for automated guided vehicle what you have is a mobile robot which can follow tracks on the mid on

so its not [ended] if you to move anywhere in the on the factory floor there are tracks led on the ground either using reflective paint or using wires

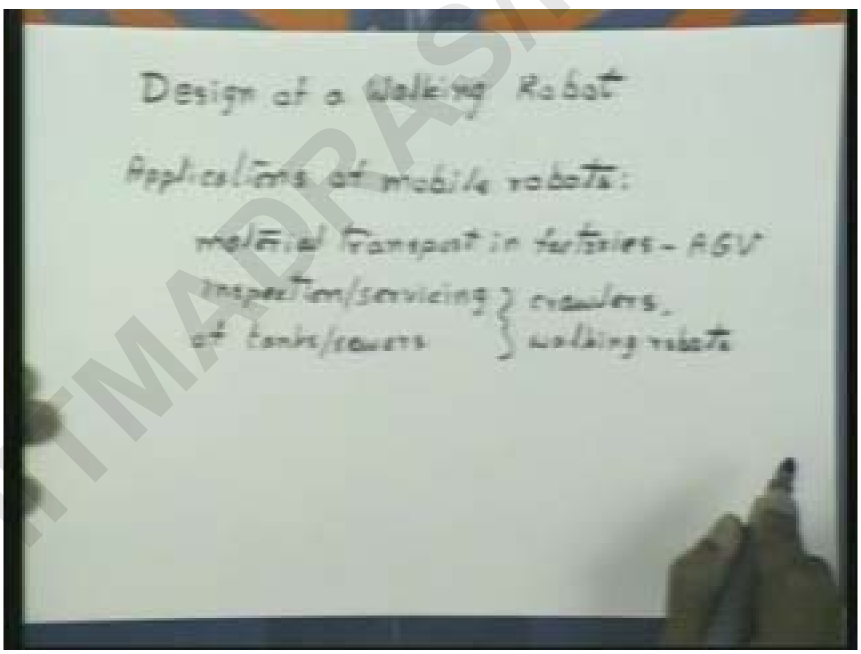
so there would be sensors on the robots which can sense um the plain the light reflected of this plain or the electromagnetic radiations which are there in wires which carry currents and with though sensors its able to follow the tracks

AGV AGV's are typically wheeled robots which can be used

another um set of application is for inspection um and surround as servicing like maintenance tanks pipes sewers (refer slide time 00:05:14)

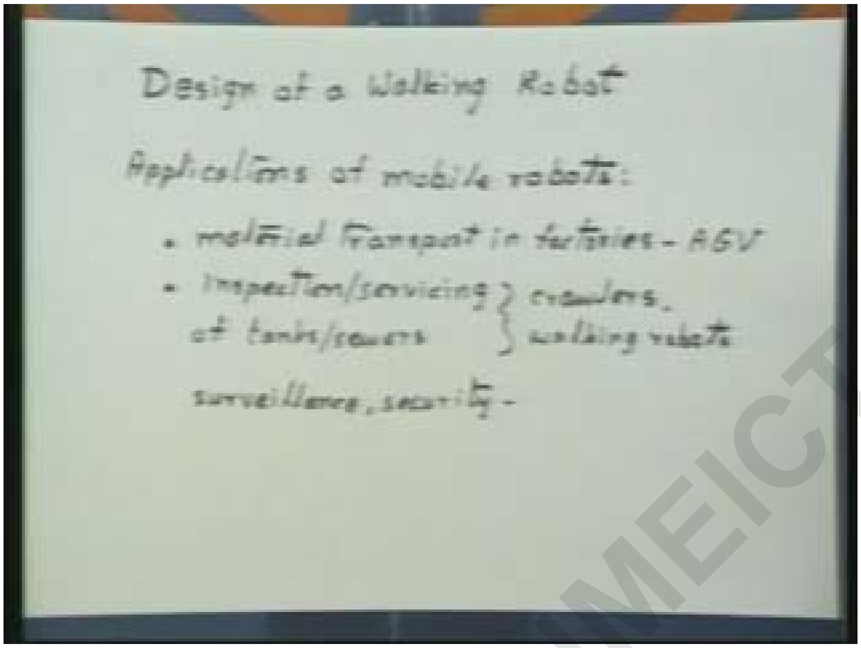


larger installations like nuclear power plants things like that what are used in this on this things like pipe crawlers walking robots um (refer slide time 00:05:39)



the robot that I am going to describe falls under this category

use um simple suppose the pipe get clogged then you need to unclog that remove the clog so what is what to be done is send a robot in locate the um obstacle and remove that another application is a surveillance and security (refer slide time 00:06:26)



typically in counter insurgency operations bomb disposal and things like that and for surveillance um what are typically used are tracked vehicles could be wheeled also but more often tracked than wheeled people have built what involve in drones
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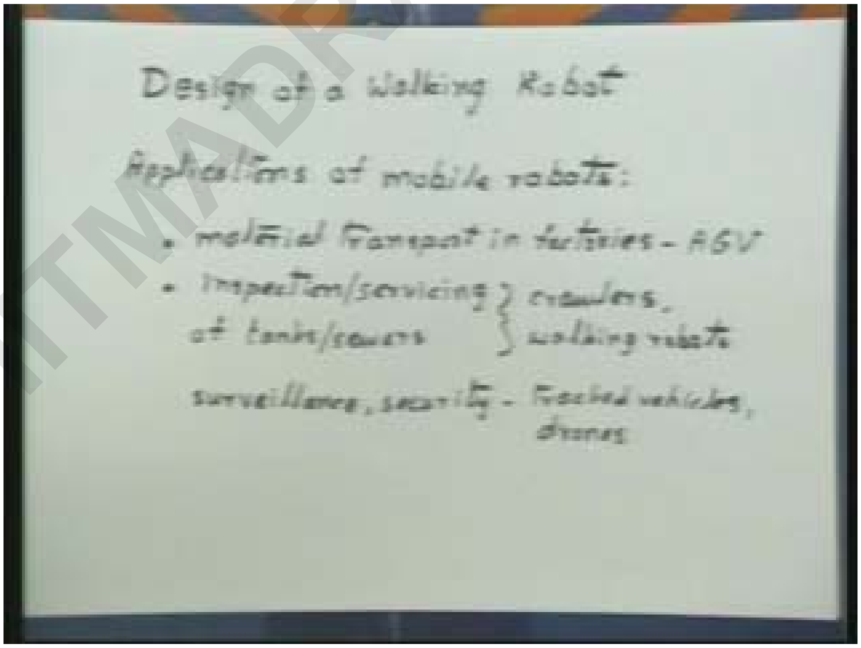
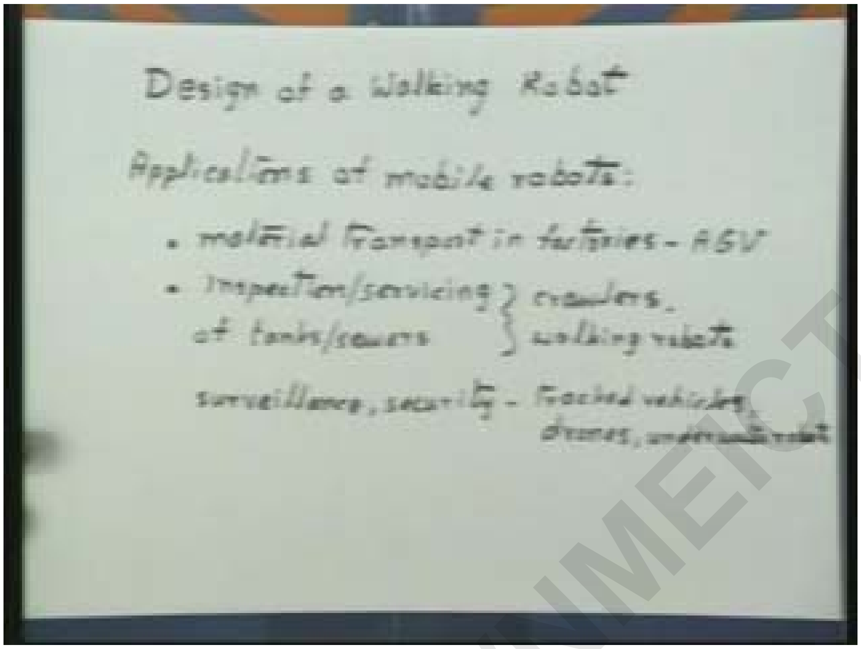


which can fly and hover and take pictures and this is some of the there are underwater robots which can also be used for this kind of activity (refer slide time 00:07:10)



so a robot needn't be mobile only on to mid on it could be in the or under water or on the surface of water

um there are have been robots used for mobile robots used for planetary observation planetary exploration not very detailed exploration but within a small region
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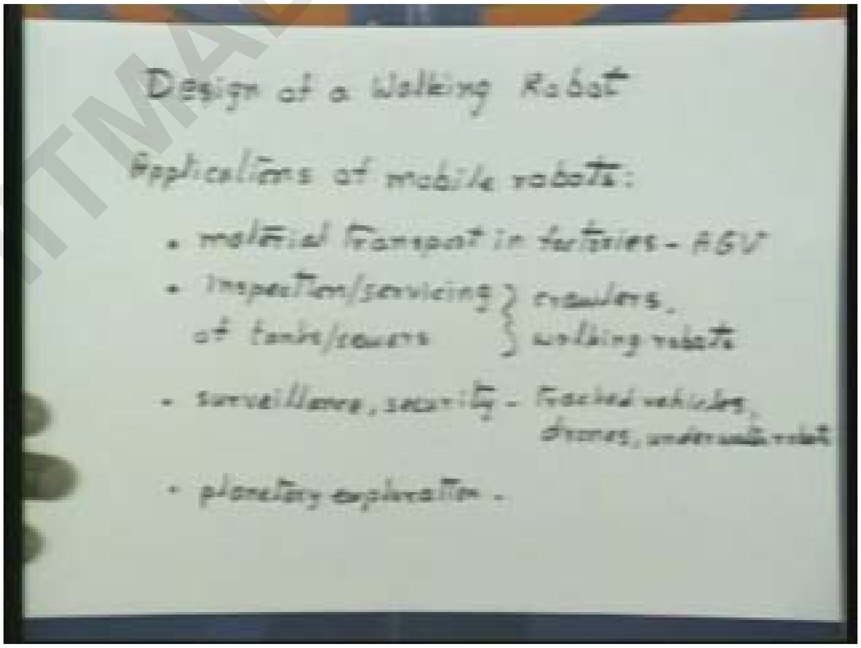


there was one sent to moon called as Donacco and that um moved quiet a distance from the surface of the earth this was sent by Russians and recently some years back um the Americans sent a mission to mars where they had this rover which could move around on the surface of mars collecting samples

there is to perform under very hard circumstances environments temperature ranging um the inside temperature of the robot ranging within a very wide range of temperatures and um another constraint for such um expeditions is that a robot has to be extremely compact and light

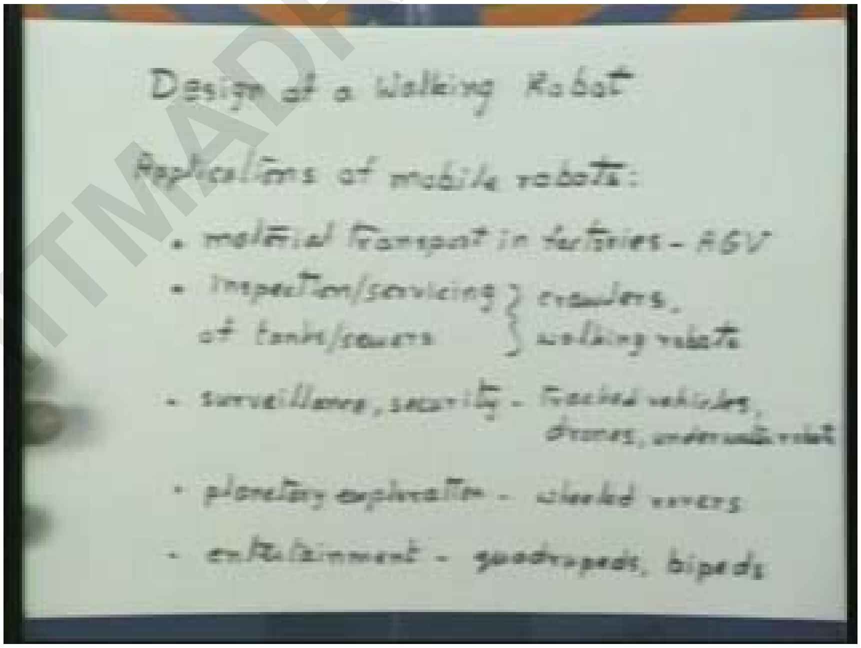
so each kilogram added to a mission to mars means several millions of dollars not just kilogram even grams could [noise] in the missiles

so minimizing weight is very critical making it robust after all they stable under big shock courses and all that and landing it has to perform reliability is a big issue

so these are very very interesting and capable mission which have been inbuilt what are usually seen are wheeled rover

recently there have been robots made for entertainment can you have you seen them ibo so quadrapeds that means falling robots bipeds two legged aasimo [noise] and um from sound it is called what is it called [noise]

yeah so it was earlier called as DR three X the later modules probably are now given more human like names so bipeds (refer slide time 00:10:03)



so for entertainment right now for entertainment and things like that but remember these bipeds are the original vision of robots something very human like a machine which can take decisions by themselves and also move around like human beings and do the work of human beings

that was the original vision of robots we have actually early ni nineteen twenties was a play which was was in the name robot first um first appeared where these human like creatures would work in factories

so it is now seventy five years and we now have something similar to that not similar to that that has to be intelligent

we can call the robots we have now very intelligent so there are several applications for which the mobile robots are being used now and mobile robots have actually changed the concept of robotics itself which got a long time with stationary robots used in industry okay

so robots have moved out into the field or on to the factory floor and ah much larger variety of robots are now being sent

soi will describe design of a robot for a particular application this we the robot was developed in robotic lab at IIT Bombay

now all of you have natraj right so ya i i just showed a few i just showed a few methods by which things move

this is its not confined to just that there are many different ways different means by which mobility can be given on the surface of a to a robot

wheeled is a very traditional way we were doing things tracked in army tanks will have tracks

we have flying machines with the rigid rings with and with rotating wings right the helicopters but now people have started using making flapping wing flying machines

under the water or on the surface of the water we use propellers to drive the to propel the robot or the boat or whatever and that is what is usually used even now

crawlers and walking machines use appendices like legs and arms right there are robots which have been made which actually cra crawled like the snake if there are no appendices okay

robots which have been made which um move the tail in order to propel itself in water like the fish or like a kneel the means of mobility which i have now being conceived and built are um usually it actually it takes um um inspiration from nature but we have gone beyond that also

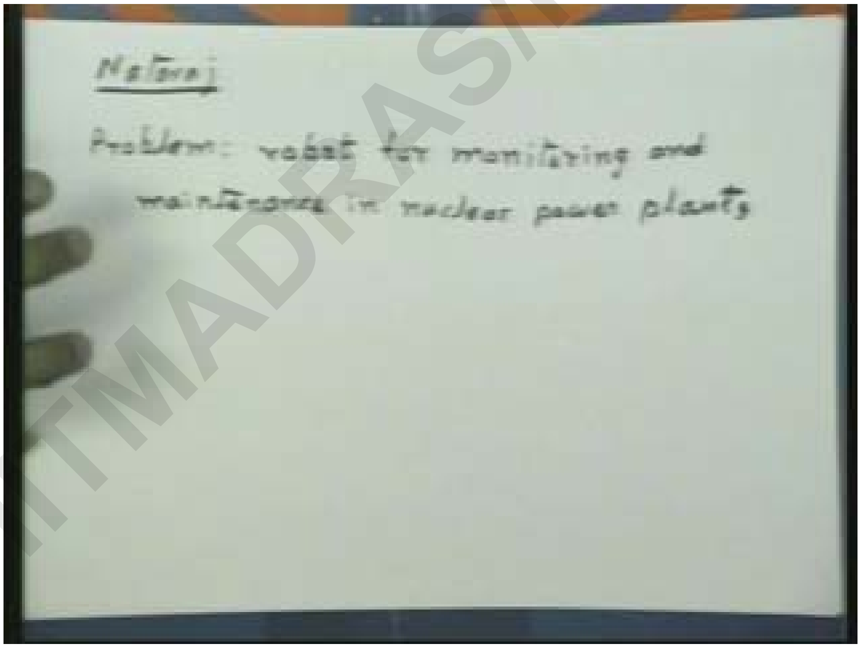
wheeled robot for example wheels you don't say nature the one of the biggest invention of mechanical engineers right wheels

the guy who invented it wouldn't call himself a mechanical engineer we would plame that he was a mechanical engineer

so there are many means of mobility that is what i want to say uh skiing right which is one way we move on very slippery surface so that can be used many ways by which we can move

so many of them have been studied now and many robots have been built which use this various means and i forgot to mention legs which is um biologically most familiar for us right

so so the the problem statement that we have for design of this robot nataraj the problem that this is supposed to solve or we had solved this we wanted to build a robot for monitoring maintenance (refer slide time 00:14:57)



so in nuclear power plants basically it has to be able to withstand the radiation which is present in nuclear power plants because um this radiation is hazardous for human beings

so there are regions were radiation density is so high and the person will not be able to work more than thirty seconds one minute at the most or he will just go in and come out and um regarding monitoring and mainte maintenance activities that is being conceived it is something very simple if you have cameras on the robot the robot can take the cameras to places where some problem is currently happening so that the the a clear view of what is happening is given to operators outside the radioactive element so that is something this should be able to do

and also maintenance would be very very elemental there could be leaks on the ground radioactive leaks on the ground which has been wiped out which has been cleaned there could be some symbol turning on or off valves also cells and things like that okay

much of these nowadays be automated by itself if you have robot there in some emergency situations you may be able to do it using a robot

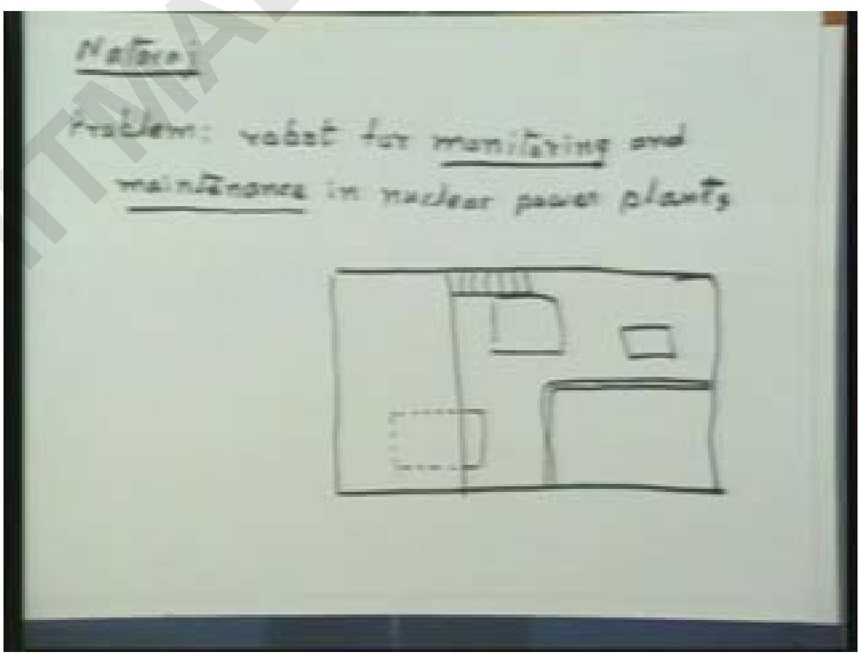
so this is the kind this is the a broad statement of the problem if you look it a little more detail the environment in which the robot has to work is some thing like this

there could be a room in which there could be some pipes laid on the ground because um human beings can step across that when we design such facilities we don't mind putting pipes on the ground right

as so soon as we put a pipe on the ground immediately it percludes many type of mobility of a robot which has to move within this

if we say wheeled vehicle it may not be able to move from this point to this point right there could be some work benches which are there there could be a higher floor to which there could be steps so there could be a mezzanine floor

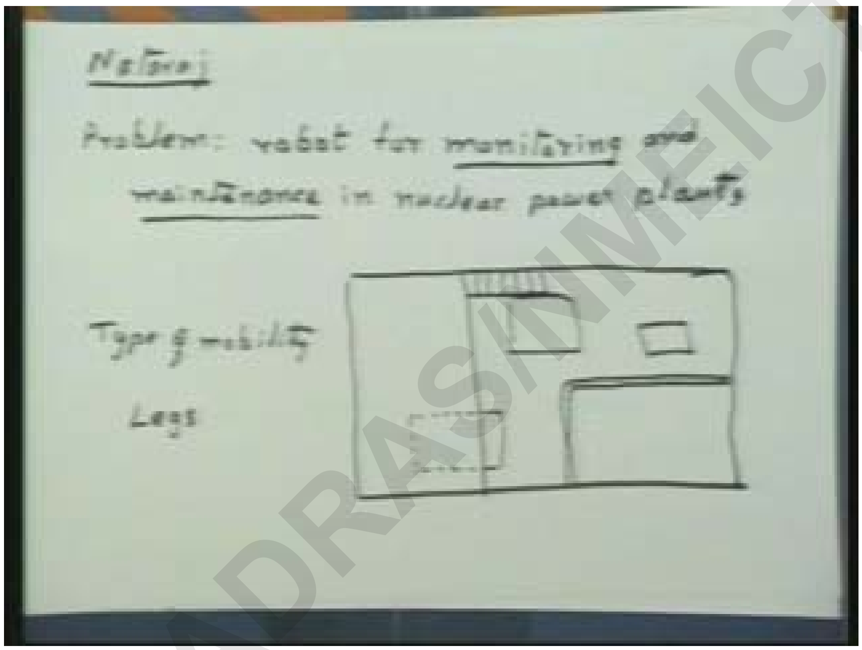
there could be a large number of workbenches or obstacles or work centers basically the robot shouldn't collide with any other right (refer slide time 00:17:40)



so it should work in a typical environment like this it should be able to move around in the space avoiding the obstacles it should be able to step across these pipes on the ground typically of the out of thirty centimeters diagonal

it should be able to climb steps on to another floor it may not be steps it may be a ram so these are typical this is a typical environment in which the robot has to work

so choosing the type of mobility the means by which the mobility has to be provided for the platform on which the cameras and hand or whatever has to be there that is a very important issue (refer slide time 00:18:48)



so what was chosen was legs mainly um the direct mapping is the this has been built for human being so human beings have legs so machines having legs probably are the best fine

but um if you look at it more detail what this legs should be able to do for us are the following

so it can step over sufficiently small obstacles it can climb staircases it is quite possible that this probably is not yeah this is also related to the environment which we saw

when we place our foot when we are walking in a region where there are some places where the feet cannot be placed we can see that and we can place our feet accordingly correct

this is something any walking machine should be able to do so selective placement of feet then another thing that happens if you have wheeled vehicle suppose the wheel falls in to a small ditch what happens on the body the body immediately gets it gets a shock right so the motion of the body is not that well isolated from the motion of the wheel

on the other hand if we have feet we have legs its possible to move in such a way that whatever be the regularity of the terrain when you are climbing a step i will very soon demonstrate how this can be done you can keep the body in at the same level in the same orientation it is possible to do that

how it can be done in a particular case i will show so it is possible to isolate the motion of the body isolate in the sense that shocks and such things needn't be passed on to that body from the irregularity of the terrain

so this is and brought in consideration i will call it perfect suspension of body
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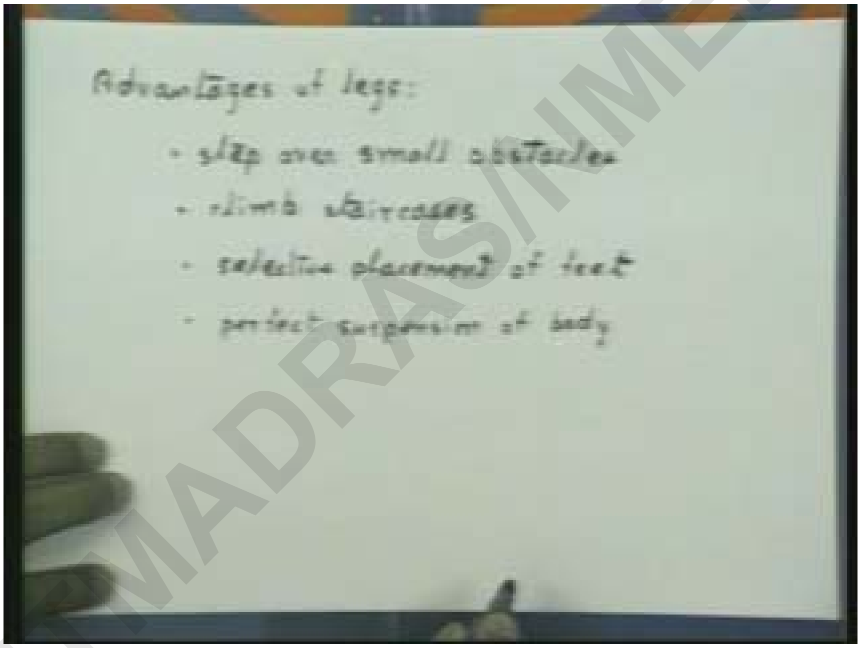
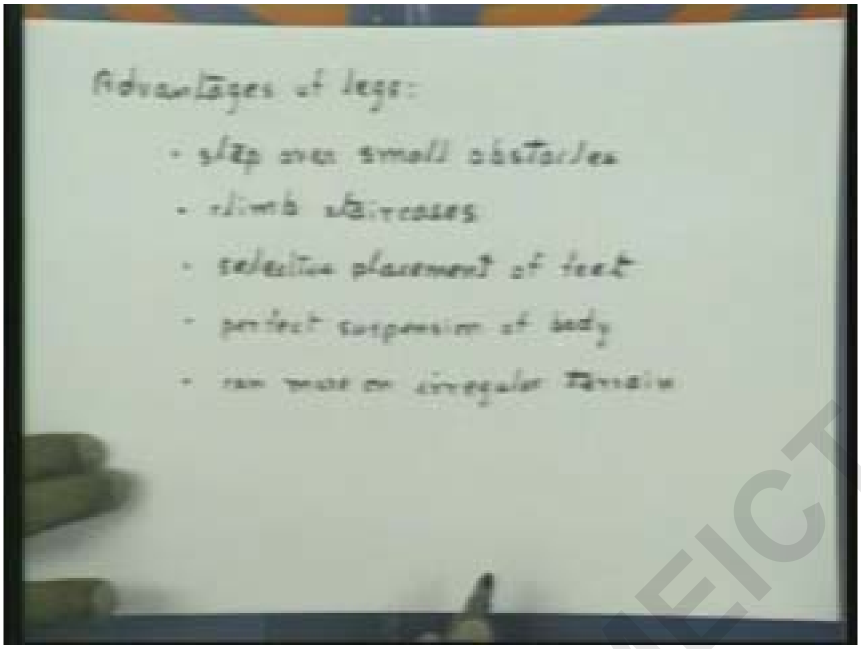


this is brought in when you are carrying a very fragile payload and you shouldn't rely on any shocks coming out

so it will be able to climb over small obstacles step over small obstacles climb staircases these are very regular objects on the ground in the environment which I showed but in general this can actually negotiate very irregular can move on terrain



so if it has to go out into the field which is a very irregular terrain which you have seen a walking um biological walking system negotiate

yeah what moves on rocking surfaces crawlers they move on rocking surfaces but anything with legs which move like the way we do or the way we three four legged animals I mean any four legged animal

yeah they can so one thing which can negotiate very irregular terrain which very steep ah sheer surfaces and things like that of course with the ledge or mountain goats

mountain goats can very easily seems to climb very steep ah cleaves without much problem without much apparent fear definitely but um it needs some foot also of course

they seem to move around move very fast over such irregular terrain and something very interesting with regard to advantages of legs in this particular environment which is a radioactive is the following

if it is if it is a wheeled vehicle if there are some leaks and contamination on the ground which is typically there the wheels eventually become contaminated right whereas if we have legs your feet you can put your shoes you can put shoes on the feet

even if it gets contaminated and it comes out it can be removed much more easily than replacing a wheel so its easy to put simple protective cover for the feet
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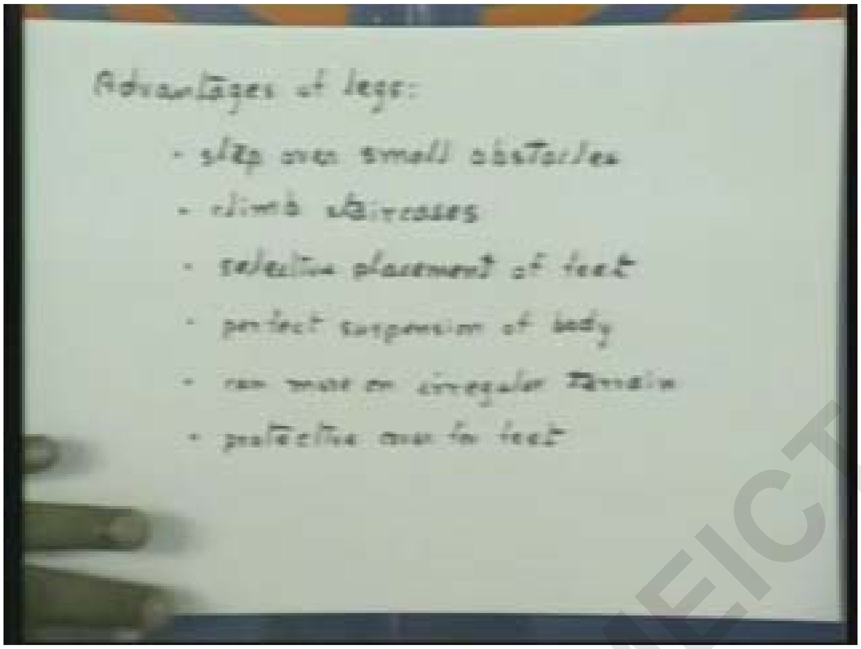

with all these advantages you would wonder why did we at all invent wheel wheeled vehicles wheeled vehicles have been there for several thousands of years actually

so why didn’t we initially build walking [noise] yeah its much more difficult actually to yes we have to take care of stability which is not an simple matter the complexity is very high in general

so many considerations are there but you have to move the legs moving of the legs is not as same as moving a wheel in general the complexity increases

if you look at the weight that usually is higher than for wheeled vehicle
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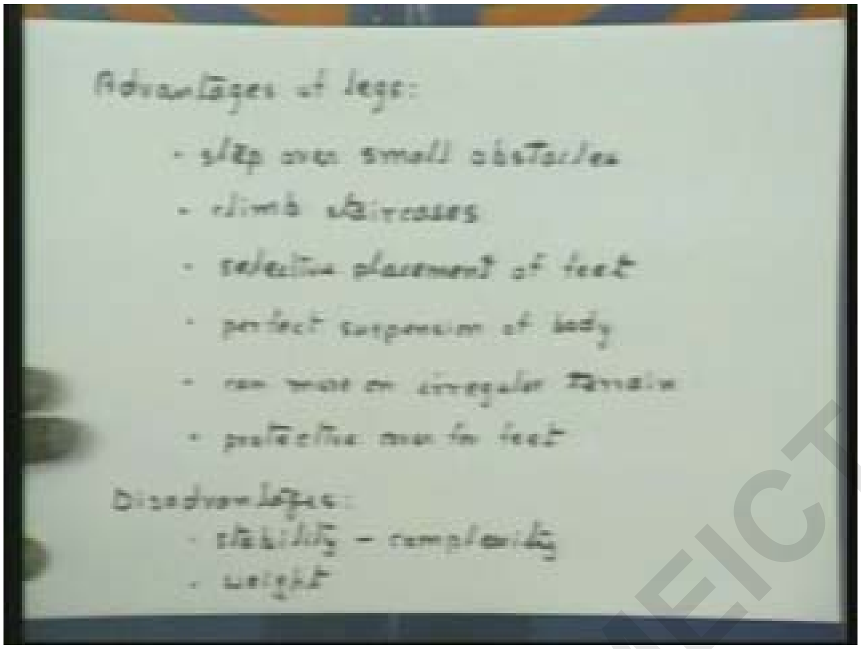


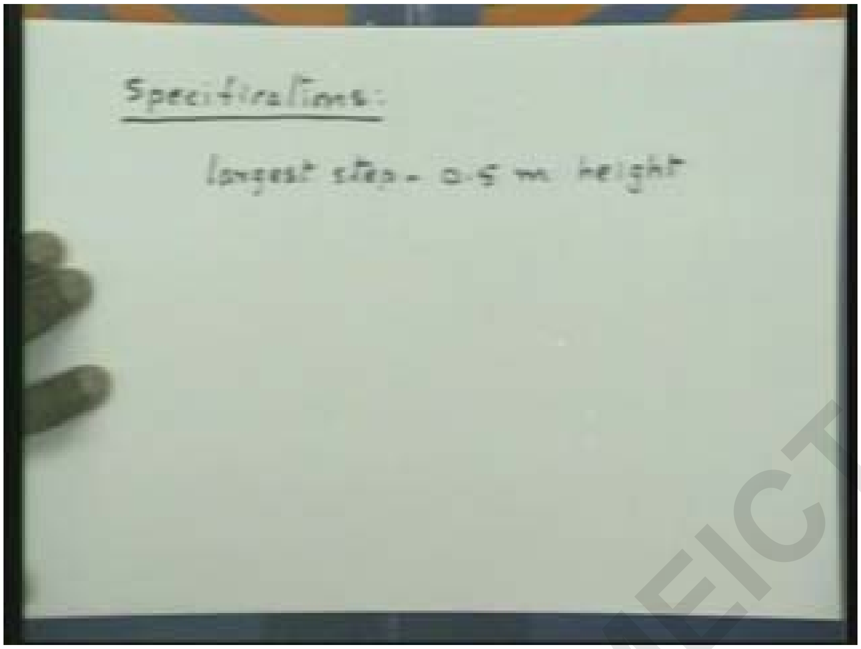
so many legs are there you have to actuate these joint so actuators are there actuators are typically electric so you need to reduce the speed increase the torque so you need gear reducers all these add to weight

so these are much much difficult to develop than wheeled or tracked robot

now let us get into the initial specifications and the initial considerations for design of this particular robot for this environment

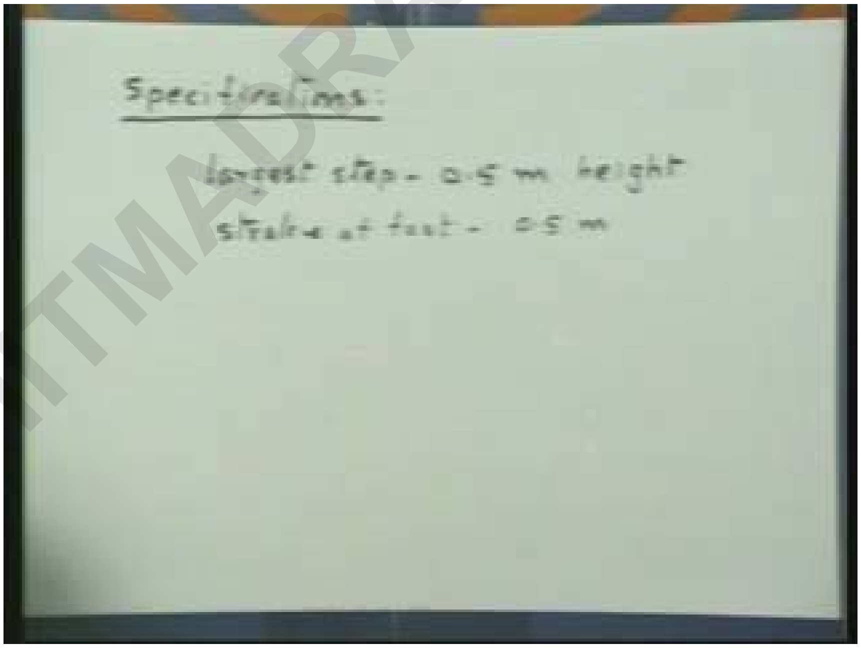
so we started out with very few specifications we wanted to leave the design as open as possible but nevertheless there are some minimum things which have to be handled

so be specified that the largest step that it needs to climb would have a height of zero point five meters (refer slide time 00:26:41)



since it has to step over some um things like pipes which are to be in the order of point two five point three meters diameter

we we specify that the stroke of the foot well how much the foot can move horizontally should be of the order of also zero point five meters (refer slide time 00:27:12)



so which essentially would mean that when a when a foot is on the ground that propels the body forward with that set of feet on the ground the body can be propelled forward by zero point five meter before it has to be lifted these are later

we also specified a ram of fifteen degree inclined which it should be inclined
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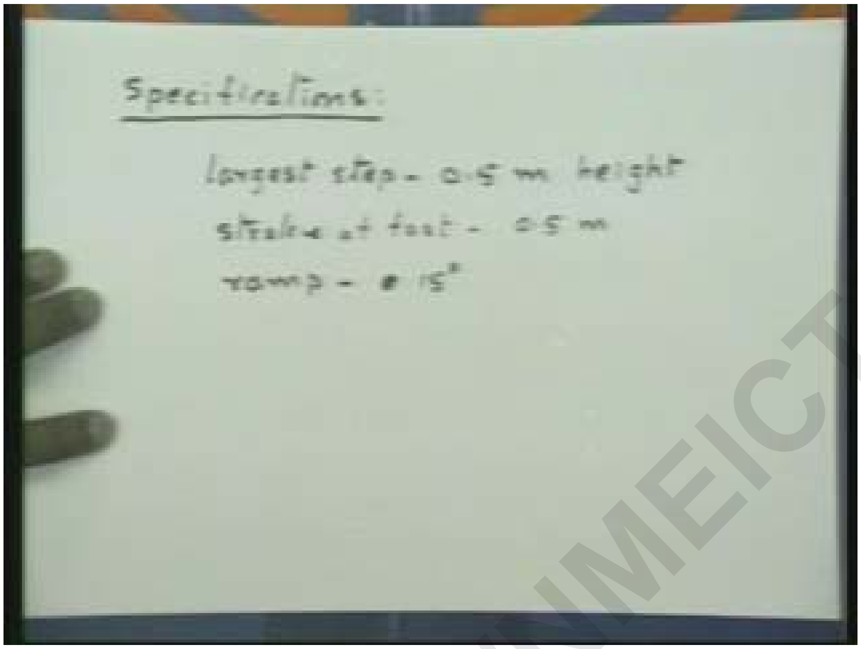
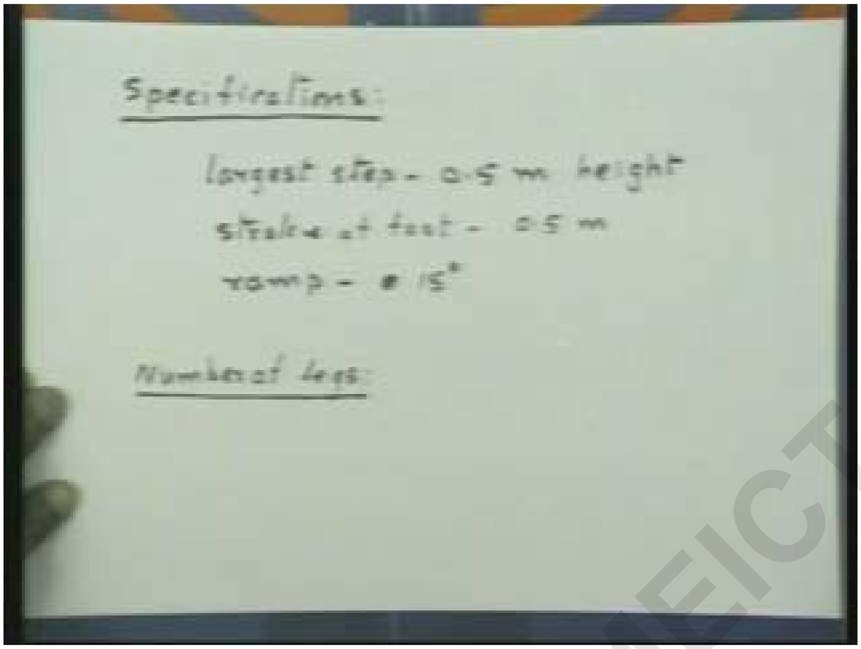


so these were the only initial specifications we didn’t say anything about the payload that it has to carry because what we are going to put there was something like a camera which is very very light and um may be an arm

but we had another idea um related to arm instead of having an arm without we can put additional links to a leg so that it can have a gripper or a hand and that can be used to do the work of a hand fine

one or two legs can be extended or enhanced in capability to work as a hands too fine monkeys do it all the time they use their legs manipulate with their legs also we can do that better

so these are the initial specifications lets look at some of the initial decisions something very simple as the number of legs (refer slide time 00:28:58)



what are the possibilities again going by nature what do you have two legs four legs six legs eight legs centipedes which are supposed to have hundred legs this is what we see today right in nature which do you think is ideal here

um two legs three three so why it three three is more stable that is right but if it is three legs in order to move the body it has to lift the leg at some point of time right

so then it gets reduced to two and you don't and you may not have stability to two its possible to have stability with that but um require some additional things

four yeah if you have four you can perhaps keep three on the ground all the time lift one place it again on the ground and lift another right there are gaits by dogs horses cats which do that

so four seems to be fine so why did nature develop six legged and multi legged [ ] roaches have six insects most insects have six then spiders have eight centipedes have even more

so suppose a dog damages one of its legs we have seen such dogs on the campus very difficult for it to move right

so this is a very important issue redundancy or reliability robustness if some damage happens can the man machine survive or do something atleast

so four we thought is not enough the next possibility is five but five is an odd number which we don't see in nature right have you seen odd numbered legs in nature I will come to one effectively odd numbered leg but typically you don't see so six is the next possibility so generally it turns out also there the possibility of having greater stability is more when you have more number of legs

so six seems good even if a leg gets cut off you may have four legged or five legged gait which is still stable okay

so why not more number of legs centipede has many more each leg means something like three two or three degrees of freedom two or three motors or actuators and all the paraphernalia which comes with that right

each joint of the manipulators stationary manipulator which you ta which you learn is something like an additional one lakh one and a half lakh of rupees

a lakh is hundred thousand rupees um so this is um siginfically additional cost so we would actually increase only after a big um it will be a big decision to increase

so we typically chose six legs so consideration was redundancy and stability another consideration will be complexity that’s why we don’t have more
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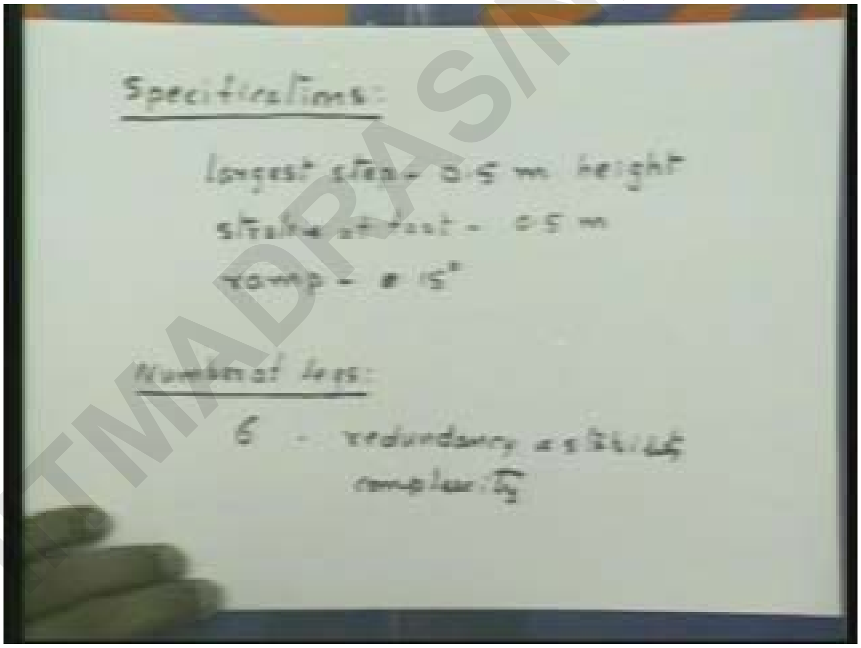


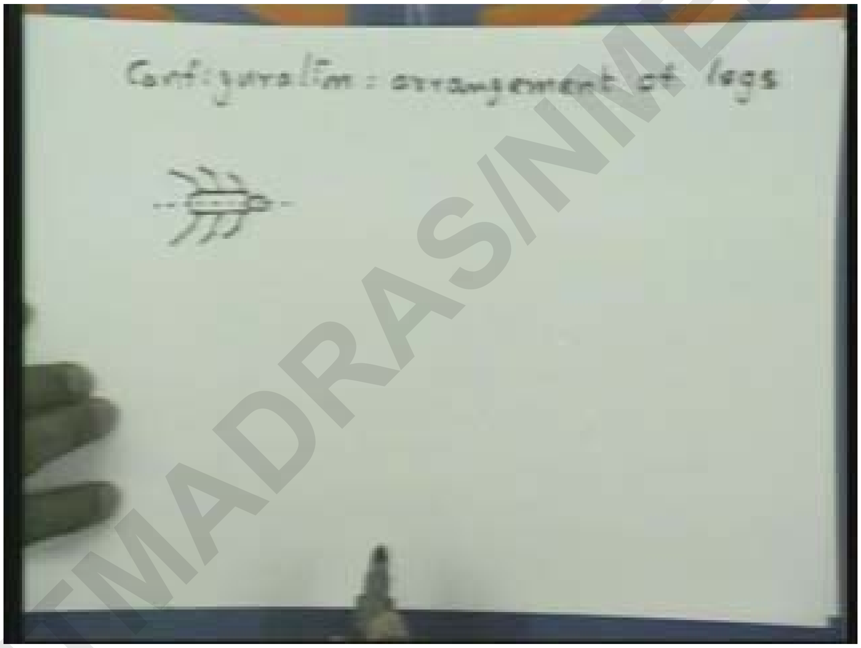
in nature the number of insects are much more than the number of mammals with four legs

so six has been a fairly common number of legs for robots four also are there i mentioned i will tell you about one legged robot so a one legged robot has been designed but it was based on a biological corresponding biological sis have you seen one leg animals biological system you haven’t actually I also haven’t but there something is moved as if it is only one leg yeah a kangaroo moves both its legs together in unison yes [ ] hops and then lands on the fore feet kangaroo stays on tool so a kangaroo appears like it is a system with just the way it moves hops with just one leg and one of the biggest development in robotics has been the development of dynamically stable one leg hopping machines okay

we have must more complexive control so number of legs six usually what that is what we chosen we probably could have chosen four and had a much lighter robot

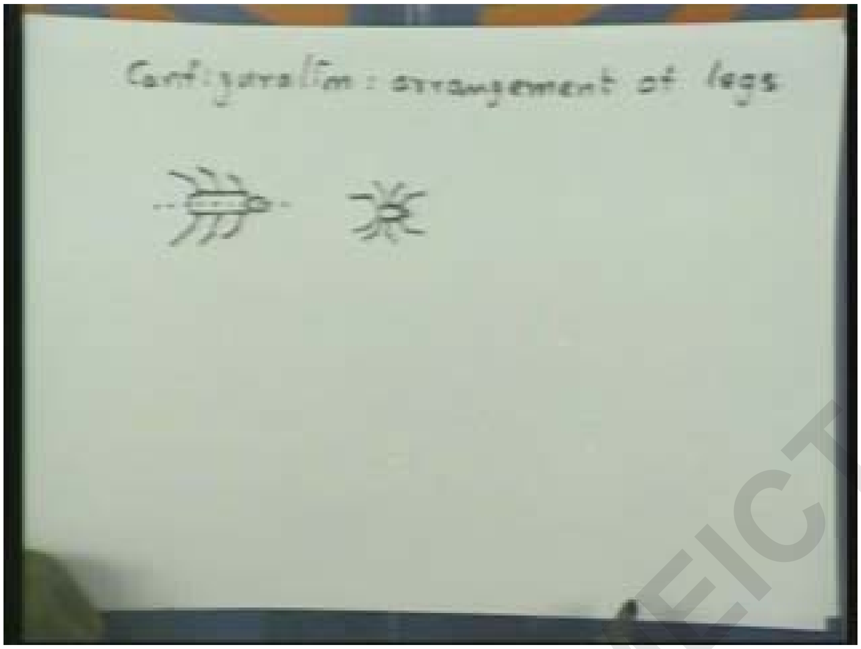
now having chosen six legs how do you arrange it on the body what are the possibilities basically arrangement of legs

so if you have seen cockroaches its somewhat like this this is a body with a head and with um legs somewhat like this the real looks a larger three legs on one side three legs on the other side this is say axis of symmetry for the machine (refer slide time 00:35:19)



and we have seen cockroaches scampering around I am sure all of you would have seen and they are very mobile very difficult to run and catch one although you are much larger imagine its very easy for a cockroach to avoid us

so this is one arrangement if you look at a spider that also has that is eight legs but the arrangement is somewhat like this slightly elongated body with a head and if you look at the legs here arranged like this right somewhat like this (refer slide time 00:36:06)



so we have all of you would have seen spiders and cockroaches which has greater mobility spiders why do you say so it can climb walls cockroaches also can its more difficult yeah that is climbing walls is another ability so I am talking about walking on level ground what do you which do you think is more mobile more mobile

spiders can change direction have you seen that yeah if you approach spider in this direction you will see that without turning the spider scampers in this direction a little bit and then move somewhere else can a cockroach do that sidewise not very easily

so this guy has a preferred direction whereas this guy is omni almost omnidirection most of the robots built have been of this type walking machines with six legs have been of this type

a typical example this this a roach by the by and this is spider so a a very important example is the adaptive suspension vehicle it weighs around two thousand five hundred kilogram a very huge machine built in Ohayo state university um mid nineteen eightees to nineteen nineties

that is a very famous ad ha machine which has this particular configuration a very famous machine which has this configuration is Odex it has only six legs instead of eight and um this has that omni directional capability

so a machine like that with six legs would be would be something like this
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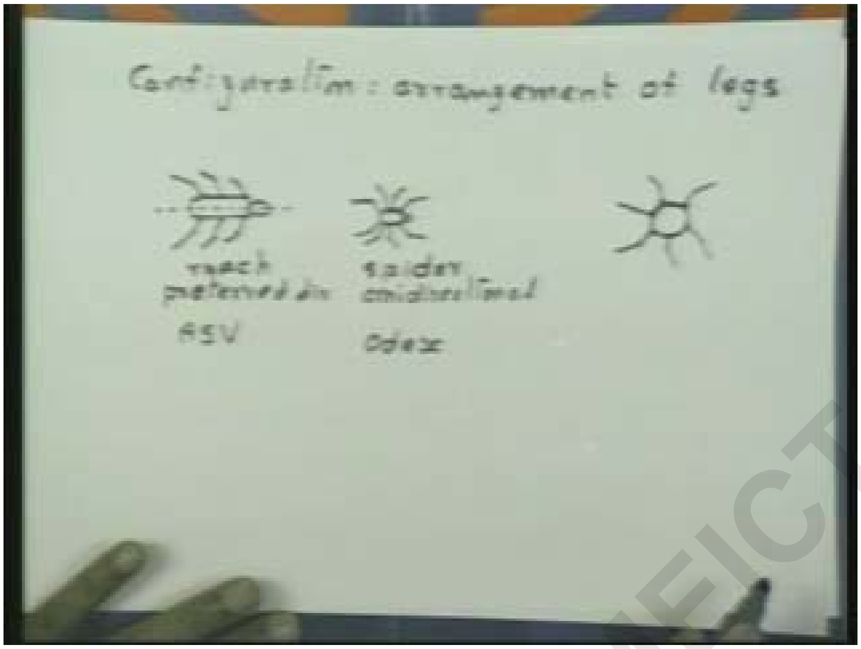


if there is one preferred direction of walking there would be six equally good directions of walking right at least six equally good directions of walking

if we design it properly any direction is equally good so this was the configuration that we chose six direction six leg axial symmetry the axis being vertical this was the configuration

so if you choose a configuration like this once you arrange the legs in a cyclically symmetric manner like this the next question is how should I design the legs

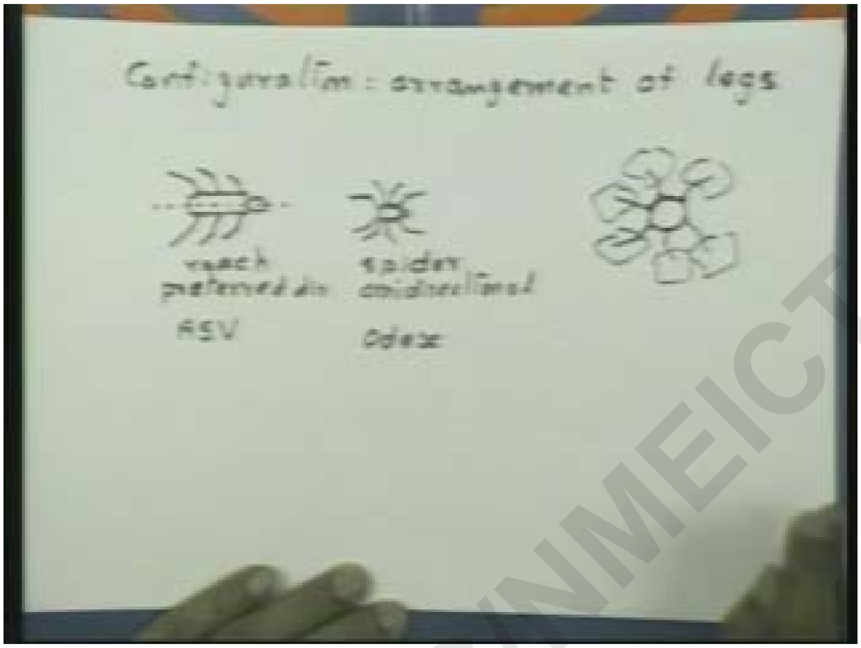
remember we what is the purpose of the leg the purpose of the leg is to move the body right so at a time there will be atleast three legs on the ground and these three legs or more legs may be on the ground and these legs are going to propel the body or move the body fine

so in order to move the body what we do is move the feet with respect to the body that is how we move the body with these feet are planted on the ground they are not going to move with respect to the ground

when you move the feet with respect to the body what happens really is this feet being stationary the body moves with respect to the feet okay

now in order to be able to give any motion in any direction that you want to the body with three legs on the ground we we would ideally like to have the workspaces of the feet we would like them to be three dimensional region in space

which means that each leg should have each foot or each leg should have three degrees of freedom right and the workspaces as I said are three dimensional regions in space so if you assumed the body to be six each foot will have a workspace like this the foot can move within this it will be three dimensional (refer slide time 00:40:54)



now what is now what will be the shape and arrangement of these work spaces with respect to the body

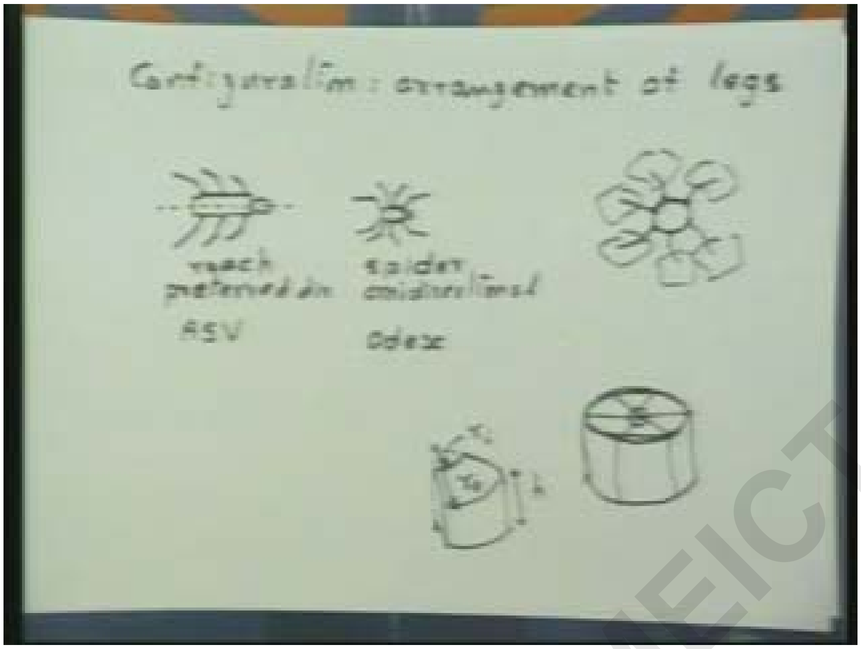
that is what is going to determine what is the size of the step it can climb what kind of vams it can climb in which direction can it move how much what could be the soak of the lay all these are determined by these workspaces fine

now what do you think will be the shape of the workspace now this being axial symmetry or cyclic symmetry about the axis a typical shape of the workspace could be something like this

they are identical so if you divide a cylinder into six equal parts what get what you get is a sector like this so a workspace will typically be a sector it will be something like this and six of them arranged all around would form it would be we expected to be something like this right

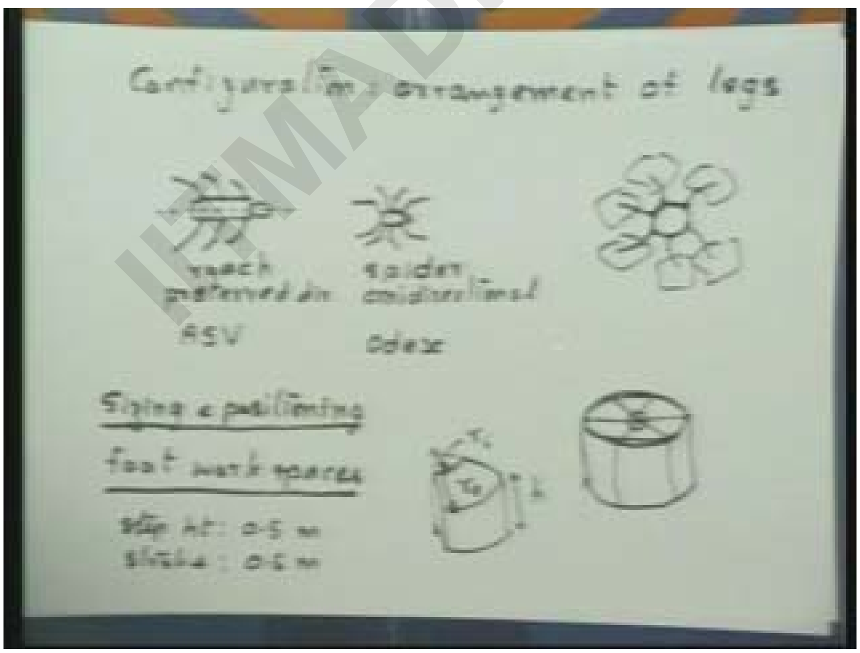
fine but that is just a sort of shape we need to give size to this what should be the inner radius what should be the outer what should be the height

these are the questions and we have to answer right so this inner radius r inner the outer radius r outer the height h (refer slide time 00:42:58)



if we this then we decided the arrangements and size of the workspaces arrangement has been decided but the size and dimension of the workspace would be decided and this has to be chosen such that our original specifications are met

not only that they are met the robot is still compact and light that sis what we would like to have so remember the the consideration for this a consideration for this are step height stroke these are two major things that we have to specify (refer slide time 00:44:13)



now in addition to this we need to ensure the following we need to really consider how it will climb the step how it will walk ant while it is doing that what kind stability it should have all this have to be really considered in order to now come out with sizes for this fine

so how it was done in our case I will describe in the next class and um I will complete discuss the mechanical design aspects and um if there is time process we will describe some aspect of the control hardware

so that you can get an idea of how the design was for this particular machine fine you have questions

you should be brimming with question actually [noise] because this is not an ordinary type of design

um it is in many of the things I have describing I probably haven't stated truly all the considerations so you should really ask questions

yeah four also a stability the reason was redundancy suppose one get leg gets damaged right that is only one of the legs simplest that we demonstrate could have other legs also

so the question to why not four legs and why six legs is mainly redundancy if a leg gets damaged then you have atleast five legs and you may be able to drag yourself out of that radio active flow

yeah it does so we have to bear that cost but if it gets damaged then you imagine people have to go in and bring it out which could um damage people

so [noise] we don't um really want such a situation but even with six legs there are situations in which that can happen okay

so we will meet again tomorrow