Wheeled Mobile Robots
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Lecture - 44
Legged and Hybrid Robots

Welcome back to Wheeled Mobile Robot. Last class what we have seen is actually like mobile manipulator as the one of the focus along with the autonomous mobile robot. So, in this particular lecture we would see like other than wheeled locomotion what would be that we have studied already legged locomotion.

So, in this particular lecture we will see what is legged robot very brief and then what would be the scenario, why it is something, what we call complex. And at the end, we will see what is hybrid where wheeled and legged robot, how it comes. So, with that we will actually like move to the slide.

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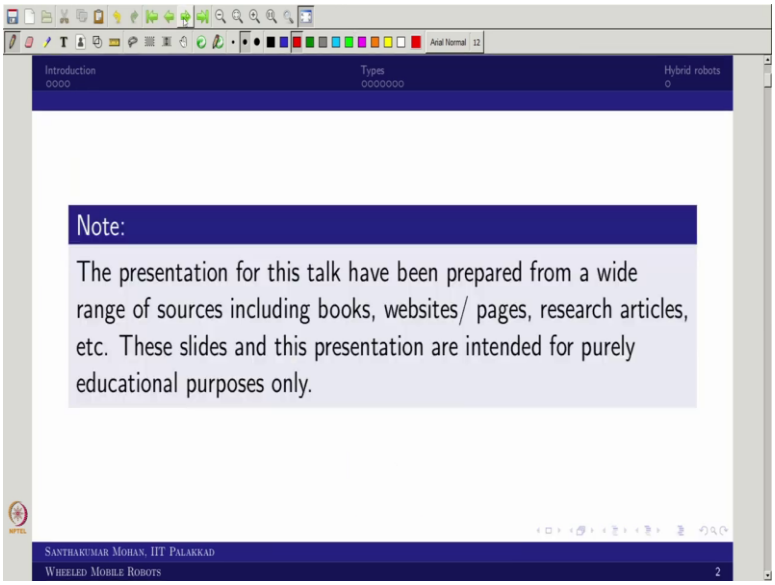

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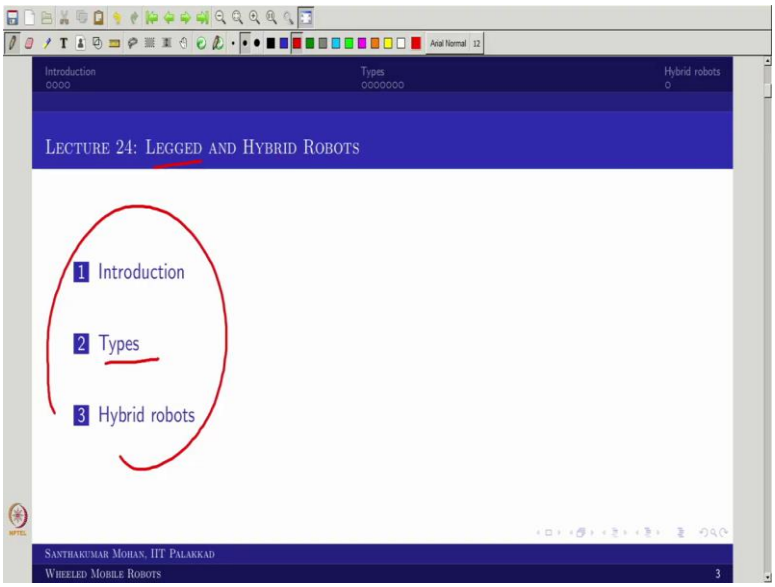

So, where you can actually like see that so you can see that here we are trying to address what is Legged Robot and what are the types and what is hybrid robot. That is what we are seeing in a lighter way, again and I am saying it is very lighter way we will see how that goes.

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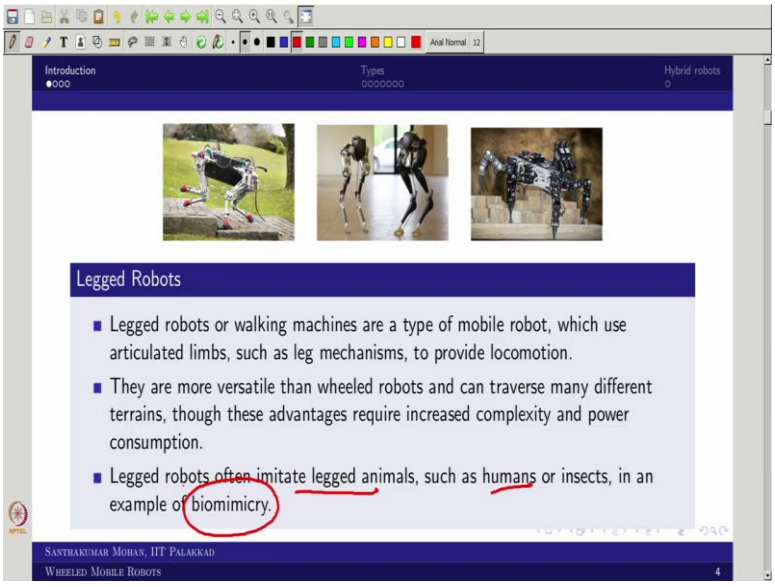

So, in that sense what is legged robot? Legged robot is what generally we call walking machines it is based on the legged locomotion. So, in the sense we have like artificial limb that would be act as the locomotive device. So, for example, you can see here it is a four wheel sorry four leg locomotion here, it is a two leg locomotion and it is actually like six leg.

So, now, what one can see in the picture itself where the wheeled locomotion's are not possible, there you can easily apply it. For example, if you apply a wheeled locomotion for this staircase climbing it is very difficult right, and you imagine this is a very smooth surface here also it is very difficult. And here you can see it is actually like on a construction site.

So, in the sense what one can see the legged robot is one of the you can say naturally inspired system, but that is having some advantage and you can say some kind of cons or you call limitations. That is what we are trying to address here. So, they are more versatile than the wheeled robot definitely because, it can transverse many different terrain whatever the terrain it can go even smooth, semi solid all those things.

But what actually like the advantage you can talk about is actually like increased complexity, but the disadvantage is actually like power consumption ok. So, but the other way around if you look at the animal locomotion the power consumption supposed to be good in legged locomotion because the friction is very less.

So, that is why I put increased complexity and power consumption, but when you talk about the humanoid or the legged locomotion sometime we put that higher degree of freedom and higher consumption, but here it is not put it in that way, ok. So, then you can see it is definitely imitate the legged animal including the you call two leg animal called human, ok. So, but what we are actually trying to say it is a bio inspired right, that is what. So, in the other way what you call biomimicry.

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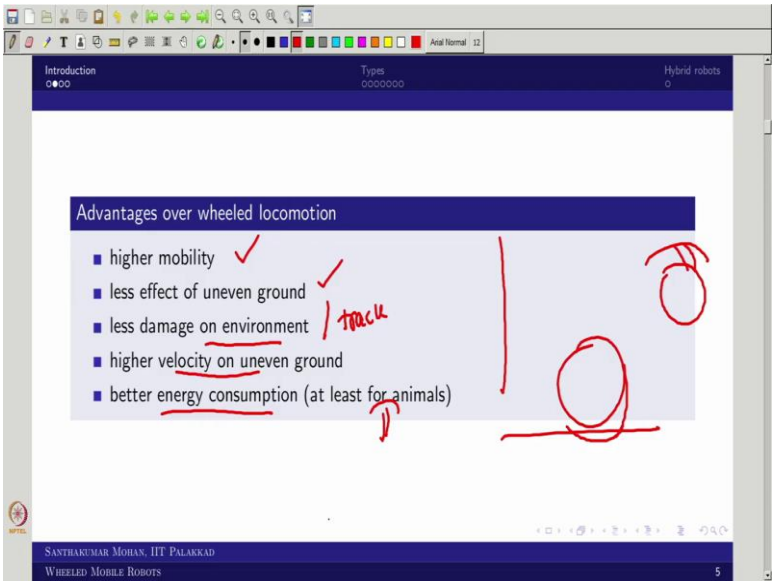

So, in that sense what one can see the advantage? So, higher mobility is straightforward, it is actually like less effect on the uneven ground, less damage on the environment if you imagine the track or the wheel that would be hitting on the ground. For example, you take a magnum wheel so, where you can see like there is a passive roller that would be hitting although what the intention is the magnum wheel would give a smooth motion.

But when you see in the real time the magnum wheel would be having a noisy and the shaky stuff. Why it is so? Because the passive roller is actually like intermittent that would be hitting on the ground. But if you talk about the legged locomotion the damage would be very less because the point contact or maximum it is actually like small area contact than the what you call the wheeled or the track.

So, that is what the idea. So, here in specific if you compare the track base so, it is actually like less damage. Then you can see the velocity you can achieve very high speed in the sense higher velocity can be attained even in on a uneven ground. So, finally, you see the better energy consumption at least based on the animal configuration that is what we want to see.

For example, you talk about humanoid, so, the humanoid would be having a 32 or 42 motors. So, then the total power consumption is high, but what here we are seeing that the locomotion motion power is very low in other case, that is what we are actually like saying better energy consumption.

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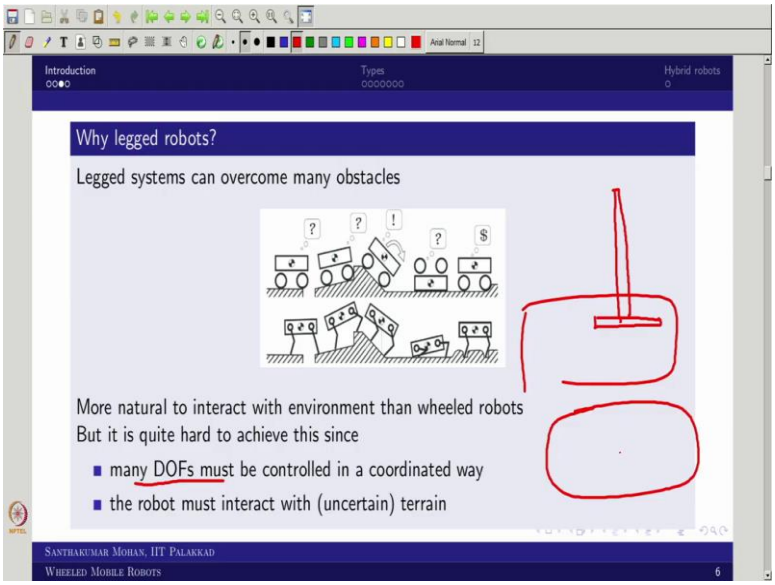

So, then what would be the case, why legged robot? So, one of the easiest way you can say it is natural inspired ok, and it can overcome many obstacle. For example, I am putting one of the picture from the very popular you can say text book. You can see that this is the wheeled mobile robot; you have actually like rough terrain that too like you can say a steep.

So, this mobile robot does not know where is the how to go from the sump, how to go the you can say bump, and as well as if it is a slope it does not know what to do. It may actually like flap and if it is actually like semi solid or you can say it is a loosely connected it does not know what to do.

But whereas, you take it a legged robot you can see it can easily overcome the sump and bump and as well as even you have a ramp which is downhill. So, there also it would be stable. You can see it is actually like getting into close to touch, but this is still it is stable, further you can see it is a loose still it is actually like making it right. So, that is what the one of the main advantage for using legged system.

So, the other system what I said it is actually like naturally interact with the environment than the wheeled robot, but what would be the additional cause or additional cost? So, it is actually like consist of many degrees of freedom that need to be control that too in a coordinated way. The robot must interact with the uncertain terrain, but what you can see, so, I am actually like giving a one stick to you ok.

So, I am actually like giving a stick to you and asking you to hold it on your hand in a vertical up position. Do you think that is actually like always possible?

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So, you can keep this pen and you can actually like move to and fro right. So, then only you can hold it, but if I am actually like I wanted to stay this is completely stand for a particular time it is not possible. Now, imagine if I am giving a larger width what you can see? It would be standing. For example, now I take this pen and put it in a probably a circular disk and keeping it, so, this pen would be stay standing right for a long.

So, that is what the one of the key that is why the olden legged robot or you call specific the biped we call humanoid. So, the human oriented robot or you call humanoid robot you would have seen that their foot would be very you can say wider and the long you can say feet. So, if there would be two feet would be actually like much bigger than the original robot ok. So, why it is so? Because of the stability. Now, you can see that the stability is one of the concern in the legged robot.

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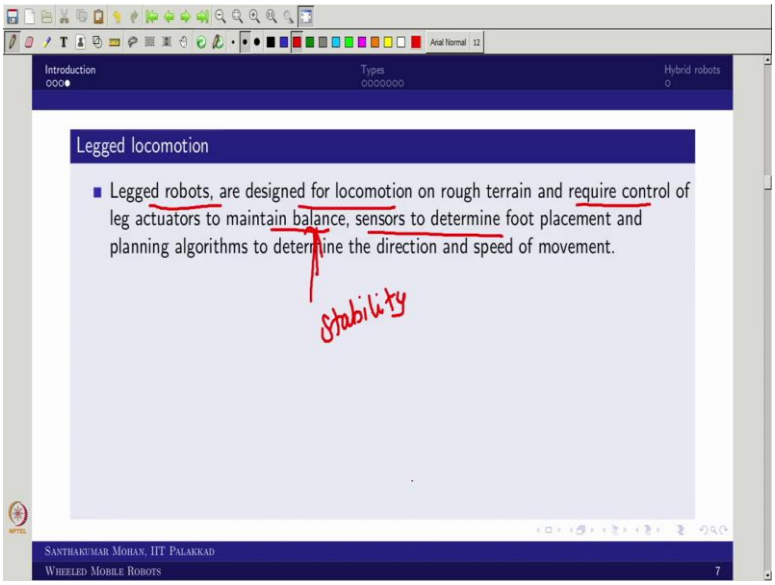

We will address that in coming up slides. So, now you can see the legged robot what it is? It is designed for locomotion motion on a rough terrain required control for leg actuated to maintain the balance. So, the balance here what we are talking about is the stability ok. So, in order to do that what you need? You need to determine the foot placement, then you have to plan the algorithm accordingly you can actually like make sure that your stability is always ensured.

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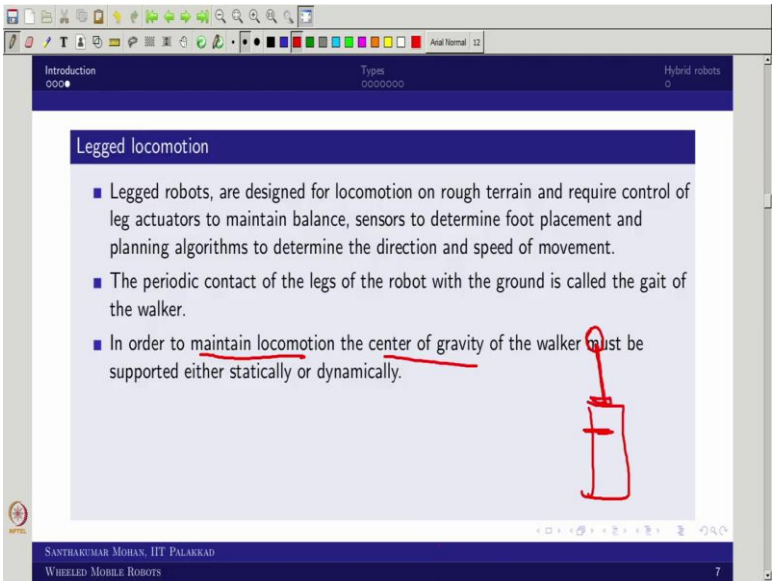

So, in that sense what you can see the periodic you can say contact of the leg supposed to be you have to monitor. So, that the periodic contact of the leg of the robot what you call gait ok. So, now the gait would be stable gait supposed to be. So, then only you can do. So, now you know like the human would be walking right, the human walking in one particular style that is what you call human gait.

So, now you take a probably a panther. So, the panther is running right that is having one particular you can say gait pattern. So, these are actually like what you call the periodic contact of the legs. So, that is what you call gait. So, now in that sense what you need to know? So, in order to maintain the locomotion, so the center of gravity of the walker must be supported either statically or dynamically.

So for example, now I am standing in this way, so now, you see that my I am keeping one rod with some mass, so, I am actually like keeping it, if I move this bar this would actually like maintain its vertical position right. So, what then? Then I am trying to do this dynamic stable.

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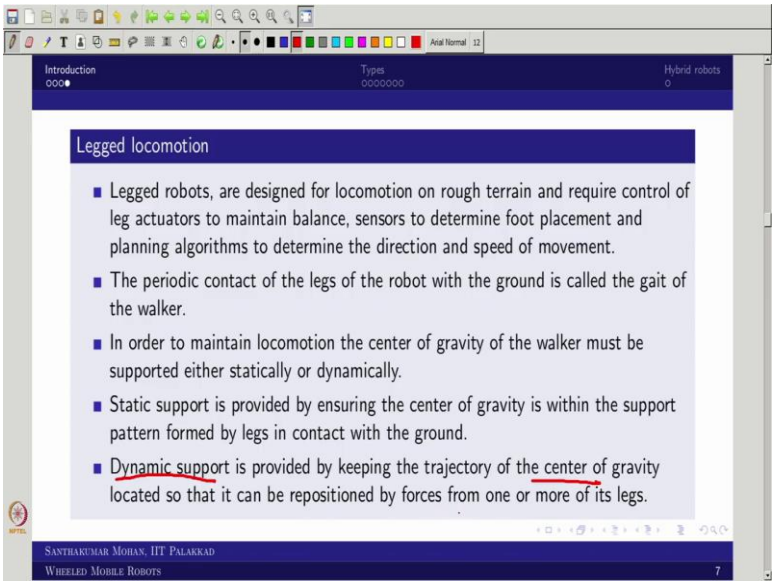

If I want to make a static stable, then I have to have a broad width foot right. So, that is what we are actually like trying to address in the sense you need to come both static and dynamic equilibrium. So, usually you take a cycle two wheel right bicycle. So, if you actually like take the stand and you are actually like keep the cycle in that way, do you

think that the cycle will be stable? No, but now you start moving it you can see that the cycle will not fall why? It is dynamically stable.

Now, you stop the brake without holding your leg you can see that the cycle will fall either way, otherwise you have to sit in some way that your cycle would be actually like maintain that stable position. So, that is why the same scenario you can apply to the legged system where the static and dynamic balancing is required.

For that one of the critical part is center of gravity that is what we are actually like trying to see. The dynamic support is actually like the other way around there when you are moving the center of gravity supposed to be located and repositioned the force according to the center of gravity acting ok, so, that is what one of the critical part.

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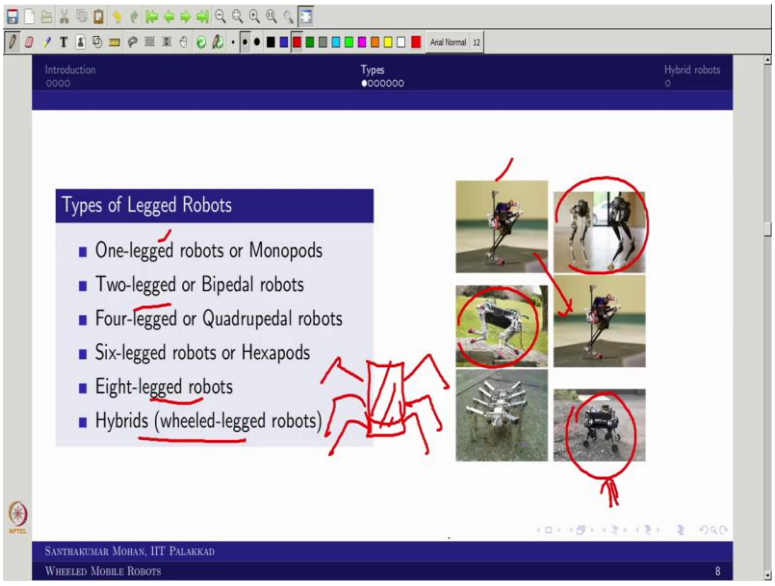

So, how that would be achieved? That we will see. So, before that you know the legged the robot can be classified in several form. So, we are classifying the legged robot based on the number of leg. So, if it is one leg like this it is what we call hopping robot we simply call monopod, pod means actually like leg, so, it is monopod means single leg, ok.

So, then you can see this is actually like two leg which is we call biped or bipedal, which is actually two legged robot and there is three leg is not common, so, then you can see the four leg which is we call quadrupedal. So, then you can see that the eight leg ok; then

the six leg is actually like probably duplicated here, the six leg is actually like another one which is we call hexapod.

So, for example, this is what you can call. So, it is actually like six legs so, it is called hexapod right. So, now you can see that a eight legged all those things, but what you can see even the legged robot further can be classified by combining wheel, so, we call wheeled leg robot.

But this wheeled leg robot we take it in a hybrid robot as a separate category, but some of the you can say standard textbook they classify legged robot as one of the subclass as hybrid ok, but we are talking as a separate category.

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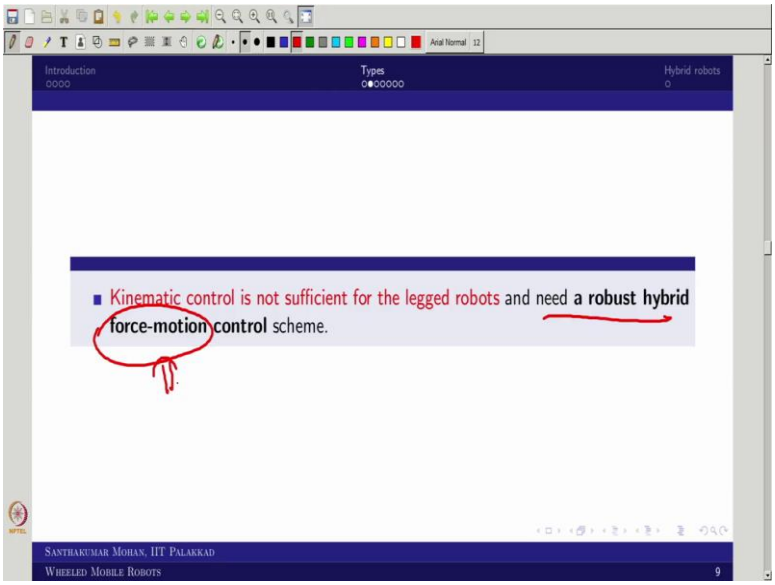

So, let us actually like move further. So, what would be the biggest challenge in the legged robot? You know wheeled mobile robot can be controlled in kinematic level, that is what most of the people are doing in mobile robot in general wheeled mobile robot. But that is not sufficient in the legged robot, why? Because, the stability is supposed to be ensured right, so, one of the easiest thing you take a pen so where it is actually like standing?

So, because of the support reaction which is coming outward force, so, now that support reactions are only the forces, which is actually like trying to balance your overall system.

So, in that sense you can see the kinematic control is not sufficient. So, that is what we are actually saying that.

So, we need actually like robust hybrid force and motion control scheme. So, you need to actually like monitor what would be the force acting on the support and what would be your motion. So, in the sense it supposed we combine both. So, that is one of the important aspect when you talk about a legged robot.

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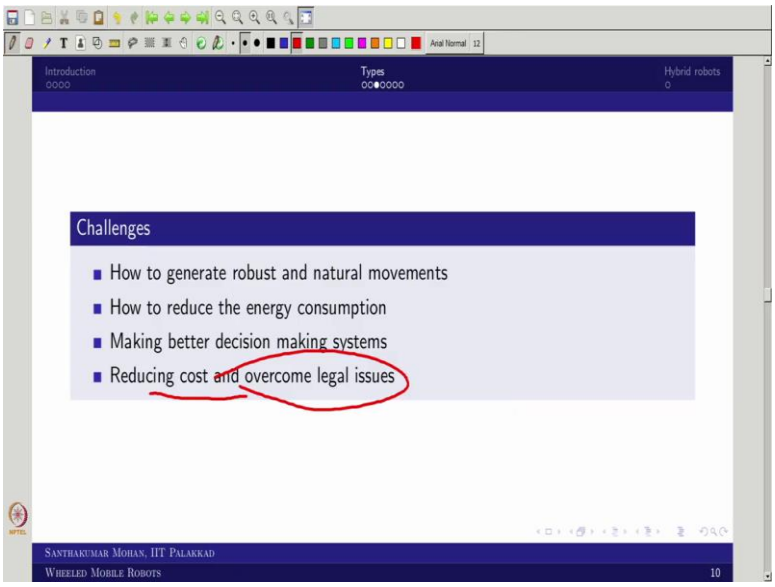

So, then what would be the challenges? So, definitely the challenge is how to generate the robust and natural movement of individual leg so, which is very complex. So, by default we are doing it. So, now imagine the just born baby and it is actually started growing, one particular stage it starts standing and walking. So, do you think that it is following the original gait no right?

So, why it is actually started learning, similar way the mobile robot with a legged can we do it that way, it is not that nature right. So, then you have to train or you have to actually like give some kind of predefined way as a gait. So, that is one of the biggest challenge. So, the second challenge you can see that how to reduce the energy consumption.

So, in the other case where we said that you can say better energy consumption we call it as one of the you call advantage but, here we are saying that reduce energy consumption

why? Because, there are several actuators will come into system for example, humanoid or legged robot why it is so, we will discuss.

So, then what you can see that the making better decision making system. Why it is so? Because, the legged system is actually like moving so, it has to do both hybrid and motion control right. So, now you have to make a decision where to change and how to change. For example, now it is actually like standing in one pose and it has to take the next to pose, so, now the decisions supposed to make it.

For example, you take a Honda ASIMO robo you would have seen in several videos and even you want you can actually Google it or you just YouTube it so, you can just type it a Honda ASIMO. So, it will come, but if you closely watch it whenever any task given to the Honda ASIMO it will come to one particular you can see home position, then need start the new task, why?

If you are actually like for example, it is dancing and you stop and ask to run it cannot do it, why it is so? Because, the stability is one of the biggest case. So, that is why you have to make the better decision making system. So, how to actually like overcome that? So, then the final challenge is actually like how to reduce the cost and overcome the legal issue.

If it is a legged robot this is very you can say similar to what you call humanoid right. So, how to actually like overcome that legal issues, where you can actually like employ into you can say in a day today life? So, if that is the case what one can see these challenges all actually like quite open and some of them are actually like try to attempt, some of them are still open and still it is upcoming.

So, that is why you can see that the humanoid although it started probably 1980 still we are not actually likely taking at in a home. Although, there Boston dynamics actually like try to show so many you can say variant of the humanoid robot, but it is actually like not really in you can say proper shape. So, that is what we are actually like trying to address.

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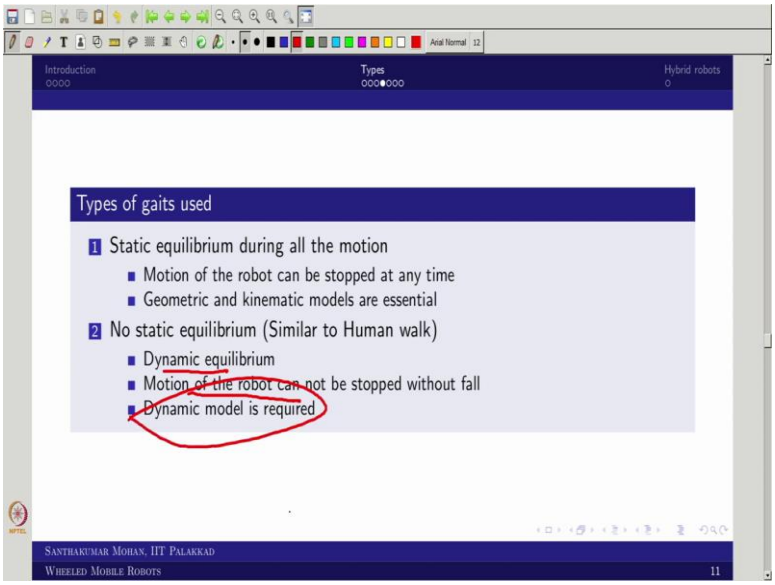

So, now the types of gait use actually like we are thinking about the static equilibrium gait. So, in the sense we are trying to duplicate as what the animal does, so try to duplicate and try to do it. So, in the sense motion of the robot can be stopped at any time if I am thinking about static gait.

What you can actually like use? You can use both forward and inverse kinematic models including your differential kinematic that are essential and that are sufficient also. But what one can see in the other case what you call no static equilibrium or the other way around?

The dynamic equilibrium which is very similar to human walk, so, there if you stop the humanoid will fall. So, that is the biggest issue. So, it is dynamic equilibrium, but the problem is motion of the robot cannot be stopped without fall.

That you would have seen several you can say fall video of humanoid. So, when you stop that would suddenly fall, why? Because, it is in the dynamic equilibrium, it is actually like having that momentum followed, it is actually like not able to stop. For example, now I am actually like probably running in a probably a speed of probably 5 or 10 kilometer per hour, suddenly I am actually like stopped probably there is a dog or something in front ok.

So, I am just suddenly stop. Do you think that I would be stable? Because of the friction probably I would be actually like moving, but imagine the robot, the robot friction is not that way right. So, that is what the biggest case, but in that case you need to have a dynamic model then you can actually play further.

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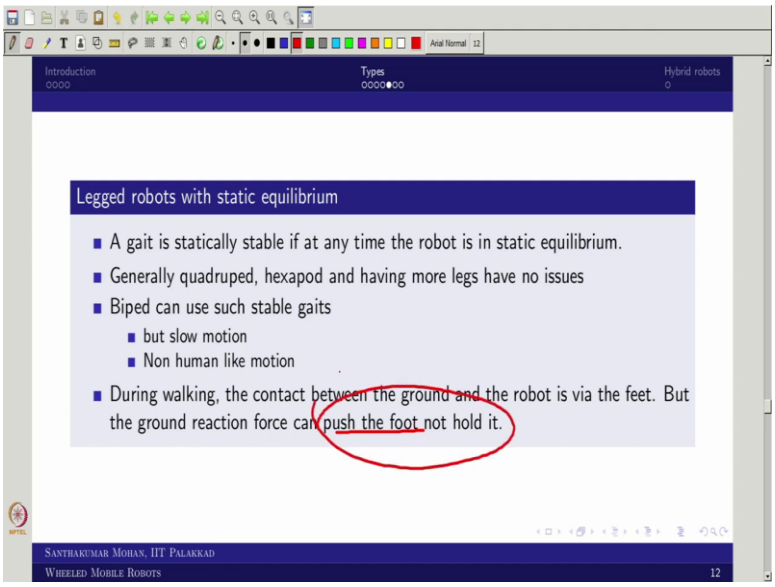

So, then you can think about the static equilibrium as the broad case broad aspect. The gait is the static stable, at any time the robot is static equilibrium. For that what we can see? So, we can take the multiple legs. So, then that is easiest because, you have always actually like stable contact at least 3 point in contact so, you can make it. But if you think about a biped, so it is actually like very difficult, so, you have to make your own.

So, then what you can do? You can move a very slow motion then you can see the static equilibrium still remain very close. The dynamic forces are actually like very much negligible. But this is not going to be look like a human like motion right. For example; you are taking a each leg like this, like this. So, then you would actually like feel it is slow, it is boring right. So, that is what happened in the humanoid category.

During walking that one supposed to know that the contact should be always actually like make from the feet and you have to actually like make sure that one critical fact what you call zero moment point or some people call a center of pressure that is supposed to be fall within the contact region.

So, that is what we are actually like trying to see, and further what you can see the ground reaction force always push the foot up not hold it. So, this is the biggest issue that is why we are not able to achieve the you can see the excellence what I have done in wheeled robots. The legged robots is not achievable because of this particular you can say limitation.

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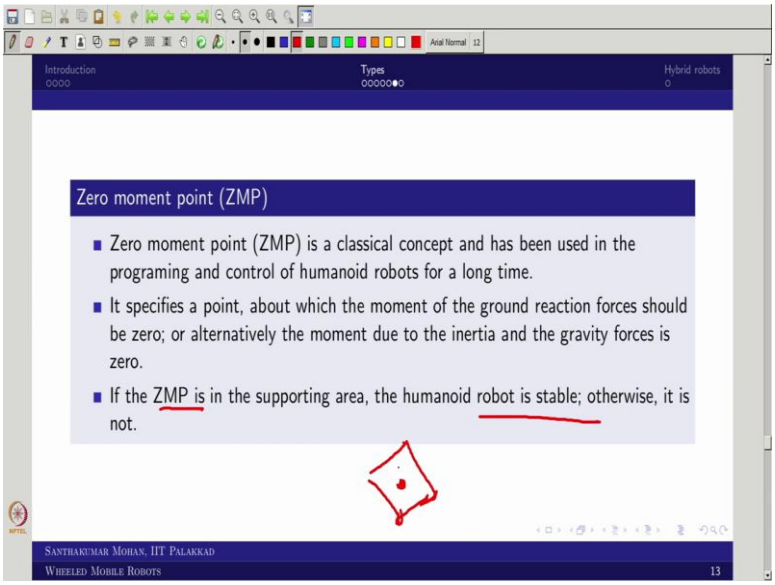

So, if that is the case what I said? There is one factor called zero moment point. What is that? So, the moment at that point is actually like zero. So, in the sense what you can say, it is a classical concept where you are actually like trying to bring one point, which is actually like you are trying to find out where the ground reaction force should be zero along with what you call gravity and reaction force, this supposed to be neutral and there should not be any moment around that.

So, that is what we are actually like trying to address. So, in that sense if I achieve that point that is what you call zero moment point, that zero moment point supposed to be always fall within the support area. For example, I have four point as a support, I draw a polygon and your zero moment point and center of mass supposed to be fall within that region of you can say supporting area. So, that is what we are actually like looking at.

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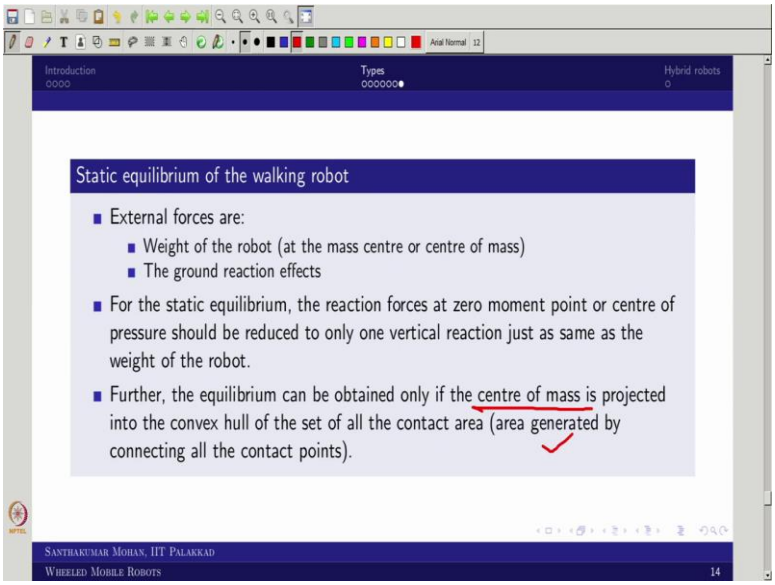

So, that some time we call center of pressure. So, then you can actually like bring the static equilibrium again. So the external forces what? So, one would be the body weight because it is static right, so, only the body weight and the support reaction. These two suppose to be neutral where? At the zero moment point. So, that is what we are actually like seeing these 2 forces are there.

Then we are actually trying to actually like make sure that at zero moment point the weight and your reaction is neutralized. So, then you can actually like obtain so but, additionally what you can see that the center of mass always actually like fall within the convex hull of the set of the contact area. So, this is what we can actually like make it. So, if you are able to do the static equilibrium is done, the similar way you can actually like make your dynamic equilibrium. So, that is what we can do.

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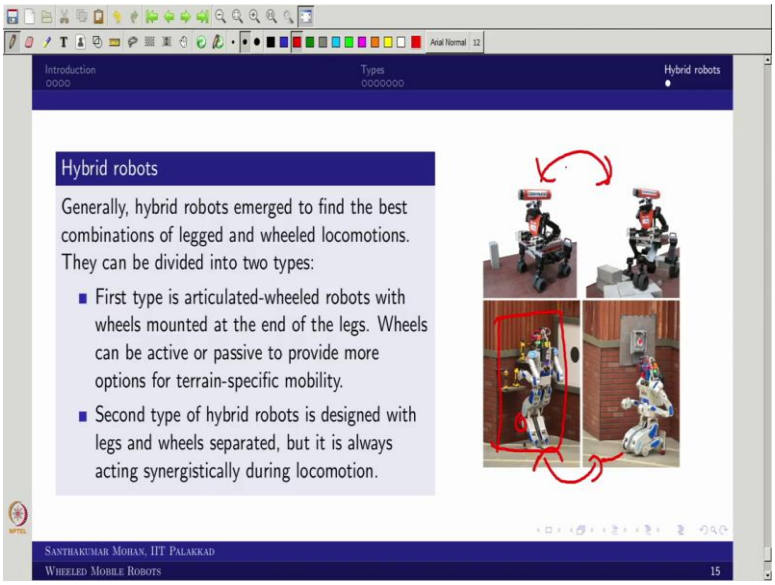

So, now what you can see? So, one subclass is what I call hybrid robot, so where the wheel and leg is connected. So, there are two way you can do it. So, what one actually like you can do? The leg is attached with the wheel at the end instead of having a foot, you can actually like put the wheel. So, then this is one class, so the other class is actually like you have two independent, so whenever you want you can actually enable it.

For example, you found the smooth surface, you move it to wheeled configuration. Whenever you are actually like finding a terrain surface you uplift and do it what you call the legged configuration. So, that is what we are actually like seeing it. So, the first type is articulated wheeled mobile robot, so, where the wheel is actually like attached at end of the leg. So, here actually like the wheel can be active or passive, but it actually like provide more option for a terrain specific mobility.

So, I will show you a picture later. So, then you can see the other type is actually like it is independent. So, where the leg and wheel are separated, it is actually like synergetically used during the locomotion. So, the picture you can see here. So, this is actually like the leg, the leg is actually like attached with a wheel ok. So, it is actually like you can see that it is actually like moving but it is actually like attached.

Now, the second case you can see that it is actually like one configuration it is like a human where it is doing a legged locomotion, but now it sees that I need to move, so, it

is actually like bend, the wheel are actually like combing into a picture and it is actually like moving as a wheeled mobile robot.

So, now you can see this is the second type and this is the first type. So, now what you have seen? What is legged robot, and what is the you can say the static equilibrium and how to achieve it and you have come across two points. So, one is center of mass, other one is center of pressure or other way around we call zero moment point, and at the end we have seen what is hybrid robot.

So, now you can say that we have started touching which are not covered in the you can say main lecture, I am just giving a lecture introduction, so, you can actually like explore yourself. The similar way we will actually like explore few other robot category in the upcoming lectures until then see you bye.