Wheeled Mobile Robots
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Lecture - 33
Introduction to Motion Control of Mobile Robots Part 1

Welcome back to Wheeled Mobile Robots. So, for what we have seen is actually like the dynamic model in the sense we started from kinematic and dynamics we have ended till now. So now, we are actually like moving very close to a real side we assume that the sensors are actually like available for everything including navigation and what you call localization.

So, in that sense what we are actually trying to see how to actually like make the control or you can say how to make the robot in a controlled manner. So, in the sense the controlled manner for general robotics will come in a very broad, but here we are talking about the mobile robot. So, in the sense the motion control is the important aspect. So, we will see how the you call wheeled mobile robot can do with motion control.

So, in the sense this particular lecture would be giving a idea. So, what is robot motion control and what are the types and how each type would be addressing and in the other sense so how we can actually like make the close loop ok. So, in that sense what one can see like we will actually like move forward.

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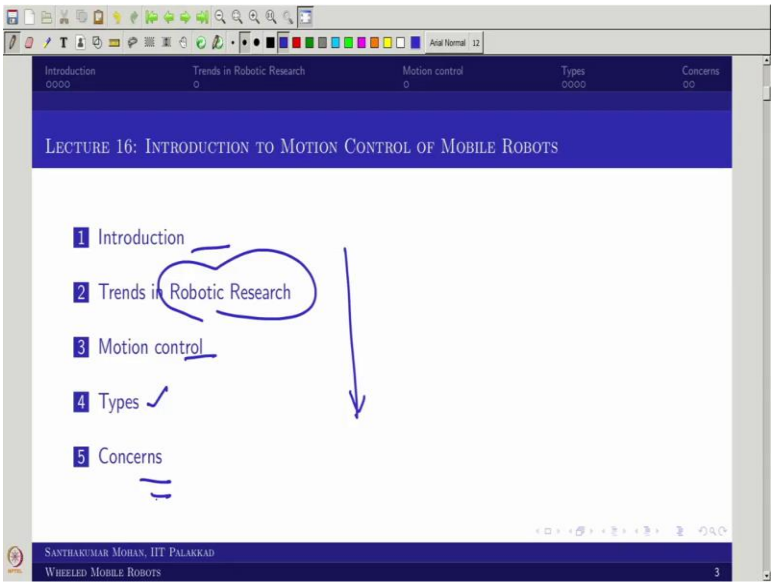

So, in the sense this particular lecture would be talking about very simple aspect, where we will be talking about the Introduction to a robot motion control. Then we will see what other trends have come in the what you call robotic research, then we will see what is motion control, what is different from other than this and then what are the types and how we will actually like take forward. So, in the sense we will broad the some of the concerns related to that.

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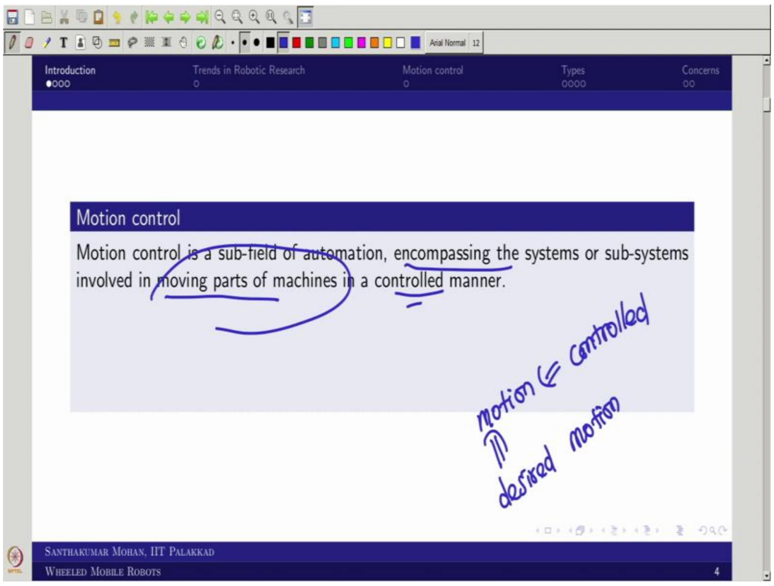

So, in the sense so when we talk about robot motion control in general, it is actually like we all know like it is also like one kind of automation, but the automation is not straightforward. For example, if I call automation the robotician will not call automation until they see a robot.

For example, you take a banking sector you go to online banking. So, whenever you open online banking you can see in the bottom or the top somebody would come as a chat box. So, it is we call chat bot, so that is also automated. You click something it is like a frequent asked questions. So, it will take up somewhere right.

So, it is actually like automatically directed, but this motion control is not that way. What that mean? So, it is actually like very very close to that the moving parts of the machine in a controlled manner. So, that is what we call motion control in the sense you have the motion, that motion you are actually like making in a controlled sense or you can say controlled manner or you call the desired motion we are achieving ok.

So, that is what in the other way around in a desired way we are trying to achieve. So, if you are fulfilling this then that is what we call motion control.

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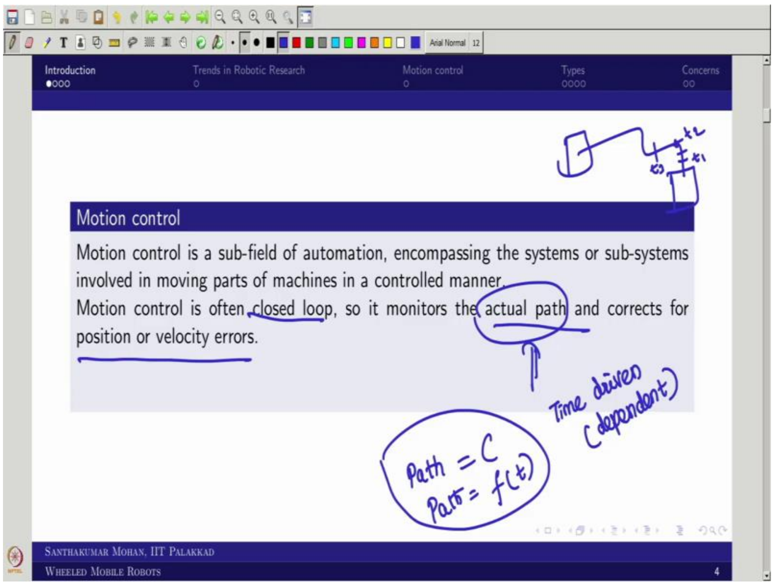

So, if that is the case so it would be involved several thing, but what generally we can see? It is a open loop to become a closed loop. Whereas, the forward dynamics to inverse dynamics is nothing but a open loop control, but here it is actually like inverse dynamics to motion control as a closed loop. In the sense you will actually like measure what is actual and what is actually like given and then you will correct it ok, so that way.

So, in the sense what one can see? So since it is mobile you can say mobility device. So, then you will see that what is the actual path. So, this path can be you can say time driven. So, in the sense it is time driven means it is actually like time dependent or time independent. So, in the sense the path is nothing but actually like I can write as a simple you call curve or the other path is actually given as something like function of t ok.

So, if it is actually like function of t that path what we call trajectory, but if the path is actually like constant, so then it is a path. For example, you take a path for example I assume that you know a probably the you can say Delhi capital to Delhi IIT you imagine there is a IIT at Delhi and you know the railway station at New Delhi station.

So, now if I actually like mark that for example this is IIT Delhi and this is what your station you I mark it. So, what this? This is actually like not time dependant right it is just a route. Now, you are giving the route just as a desire to the robot you are not defining what time, what sentence or what segment you have to stay, then that is actually like what you call path.

But if you are saying that every segment you are saying that so this is t_1, this is t_2 and this t_3 like that you are saying that, so at 5^{th} second you should be here and 10^{th} second you should be here. Then you are what you are doing it? You are giving the path along with time dependency. So, that is what you call trajectory.

So, now we are talking about both in the sense path plan you can see path following and as well as trajectory tracking. So, in the sense what one can come? So, not only position error if you are talking about trajectory, then there would be coming as a velocity error.

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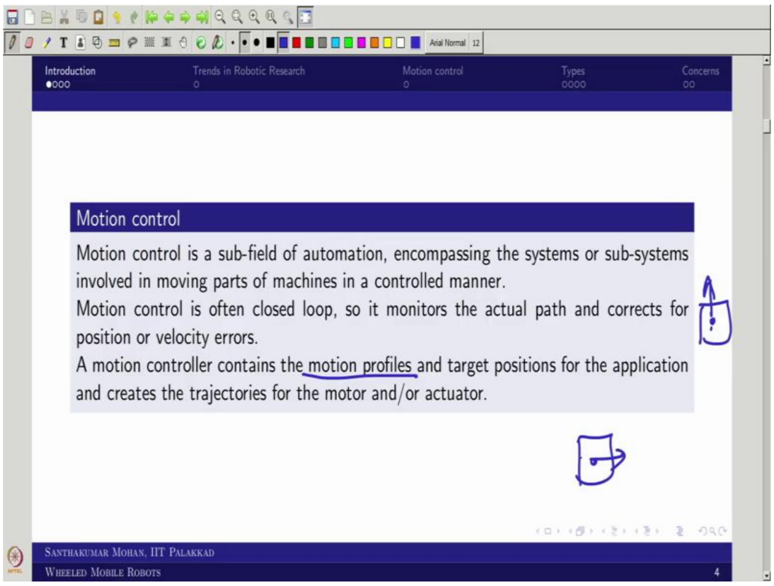

So, that is what we are trying to address. So, in the sense what you are trying to give? So, you would be giving a motion profile and some of the target position. So, this particular robot supposed to follow that some cases the trajectory also you need to create for your given motor or actuator or sometime even you have to create a trajectory for the robot.

For example, so this is what your robot location and you want to stop in this manner ok. So, this is the given and this is the final. For example you assume that this is a parking lot you need to park. So, then what you will do? So, it is a start and end point you know like some of the drivers, for example you know like in the car parking of the hotel or in a probably a big crowded layout.

So, it may take time to park right even you have to actually like have a very narrow path, you would take 2 you can say forward and backward. So, in that sense you will not define the time right.

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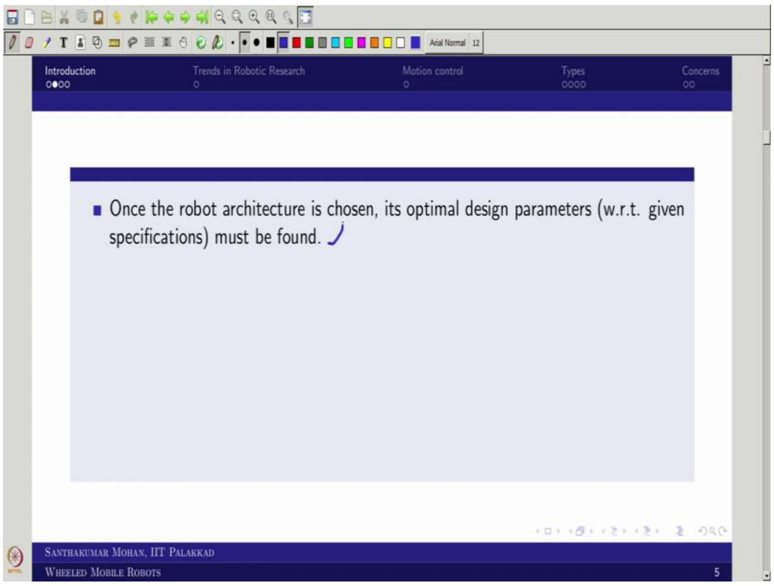

So, that is what you need to see. So, in the sense what one can see? The robot architecture is chosen with the optimal design parameter that is not enough that is what I want to put it here.

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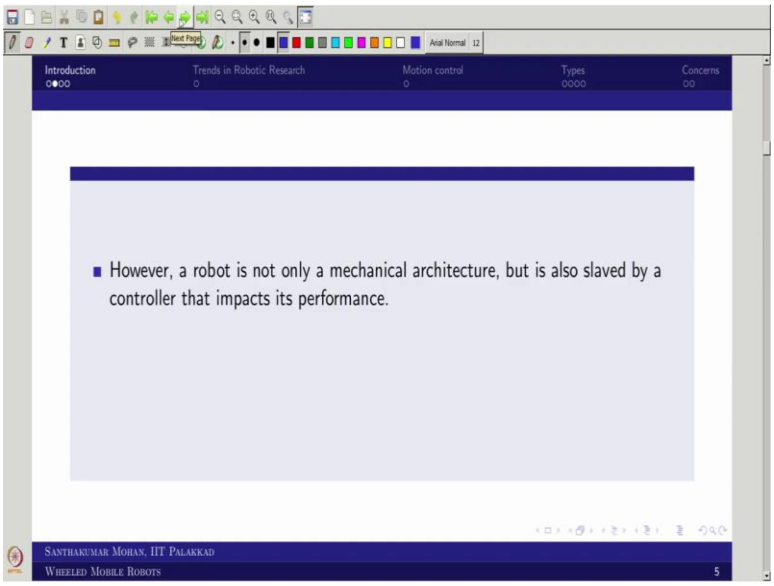

So, what that means? So, the robot performance is actually like not only depend on the mechanical architecture, it would be impact it is you can say performance with the help of controller. The controller performance or the controller influence is definitely impart the overall performance of the robot.

In that sense what one supposed to know? You have to actually like design both in optimally. You have a very rigid you can say sophisticated mechanical architecture, but your controller is actually like very conventionally which is sluggish, then also you cannot achieve the desired one or you have a intelligent control with learning base, but your system is actually one collapsible or non stable, then also you have a problem.

Very simple example you take a 2 wheel robot and you take probably 4 wheel a mecanum robot. The 2 will robot with long rot then the stability is one of the critical thing right. So, you have a proper planned detailed you can say mechanical design you made and everything is proper, but your controller is actually like not able to take out taken out the stability aspect then it is gone right.

So, in the sense what one supposed to know? The robot architecture is not a mechanical alone; it is actually like consist of the controller aspect that is what we need to know.

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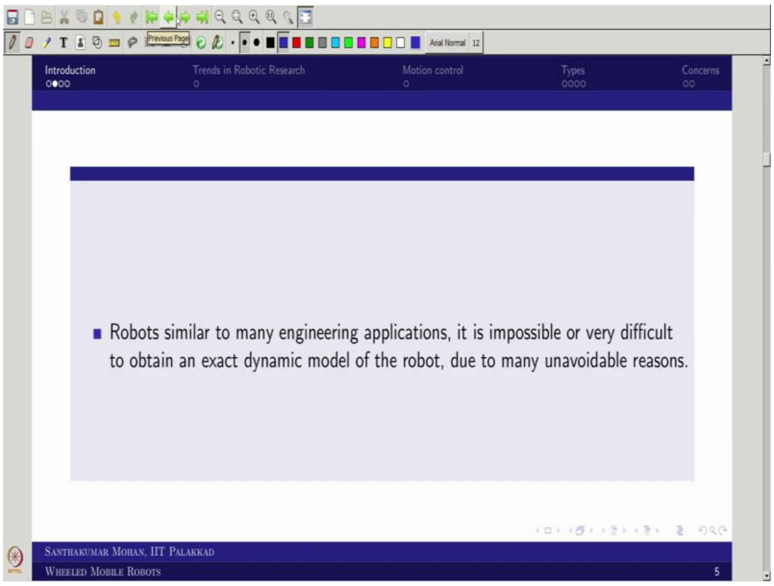

So, if that is the case what will come into a dynamic model? You have derived the dynamic model but with a very simplified way right. So, in the sense robot also very similar to all engineering application, it is very you can say impossible or very difficult to obtain the exact dynamic model.

Very simple case you can take. The wheel rolling friction you cannot exactly model it, because the wheel rolling friction will change the environment to environment even that you cannot actually like model it very closely. Second thing is although you design the vehicle you assume that it is supposed to be 40 centimeter by 20 centimeter and you assumed everything is very proper you are you call solid model is giving, you can say proper mass and inertia, but your system fabricated right.

So, when you do fabrication then you may expect some kind of uncertainties right, if that kind of uncertainty how you will address? One more addition thing when you talk about the robot is moving, so what you can see? The robot is playing in a real time environment. So, then what would be un-evitable or inevitable? So, the robot would be end up with external influence; the external influence I call a disturbance.

For example your mobile robot is moving on a probably ground just imagine. So, there is a football players playing. So now the football also can come and hit. So now imagine there is a kid playing. So, that kid is actually like taking a mud and putting on your mobile robot these all some kind of example right.

So now, they disturbance how you are categorized that is different, but definitely one you can say that; so you cannot avoid the external disturbance and one cannot actually like avoid the inevitable case which is uncertainty ok.

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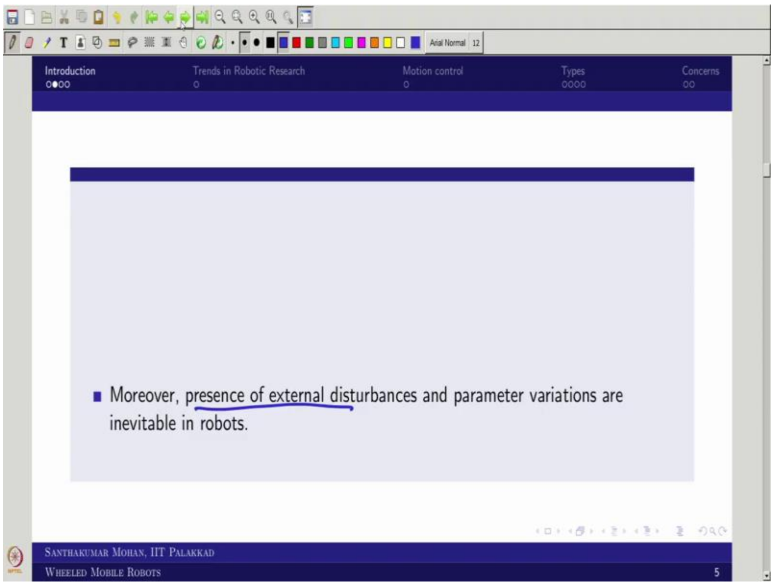

So, if that is the case what happened? The real time mobile robot would be having presence of you can say external disturbance and parameter uncertainty which is we call the parameter variation.

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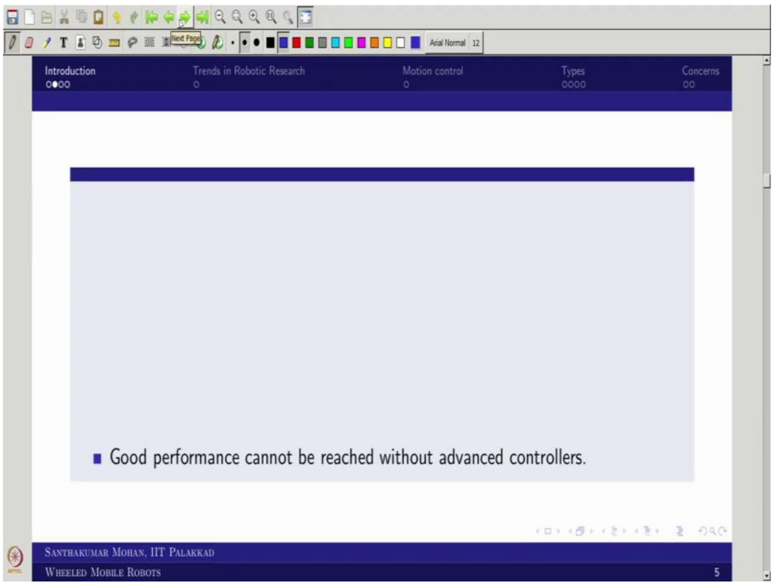

So, now if this is the case what ones supposed to think? So, the conventional controller may not work. So, what that means? The conventional controller will come with different form. So, this conventional controller will not work or will not give the good required performance. In that sense what one see? So one can see that the advance controller will play a role.

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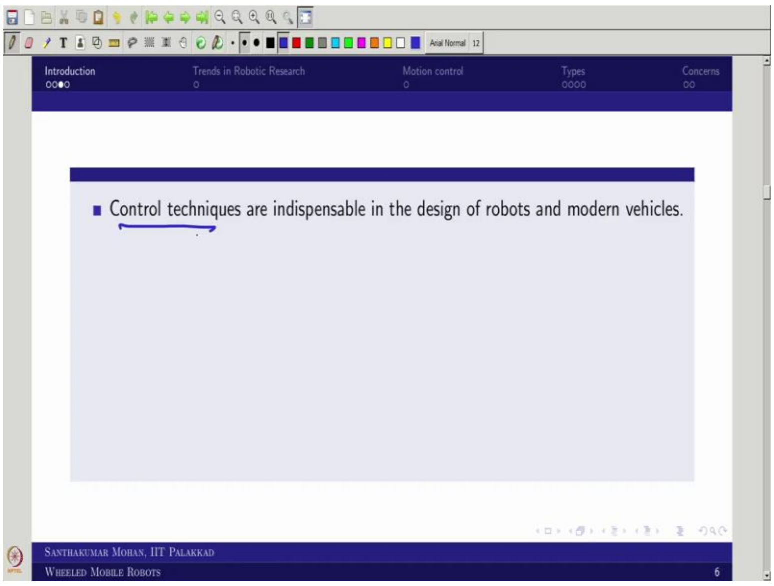

So, then what one can see, what is a advance controller, so, that what we are trying to discuss. So, what that means? So, the control technique is actually like indispensable when you talk about robots that we have seen.

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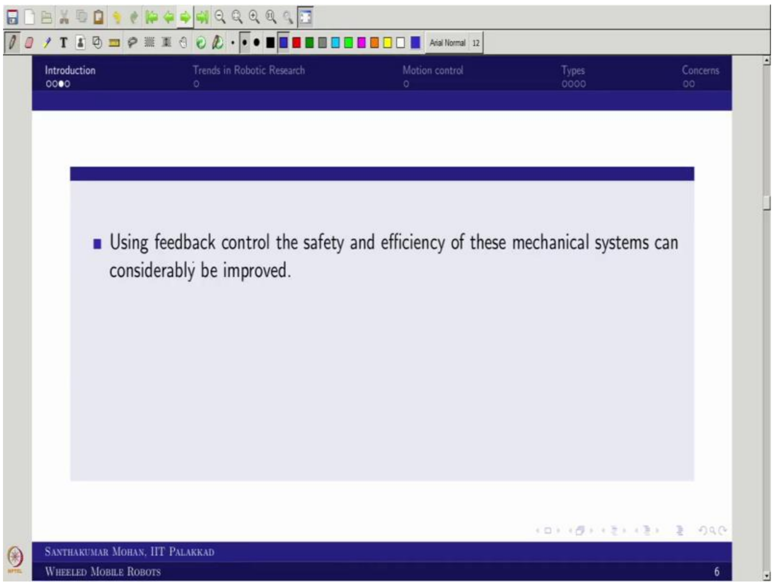

So, but what we have seen is actually like the feedback is important. So, feedback is supposed to be actually like make sure that the efficiency of the mechanical system considerably improved.

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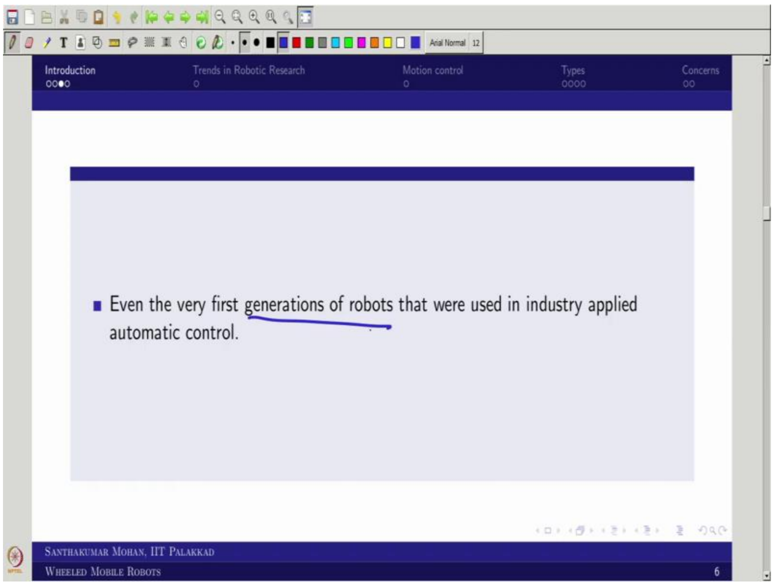

So, if that is the case what one can see that the generations of robot, even the first generation was having a automatic control. Now, in that case so I need to discuss about how the trends of the robotics have come. So, that is what I am planning to discuss.

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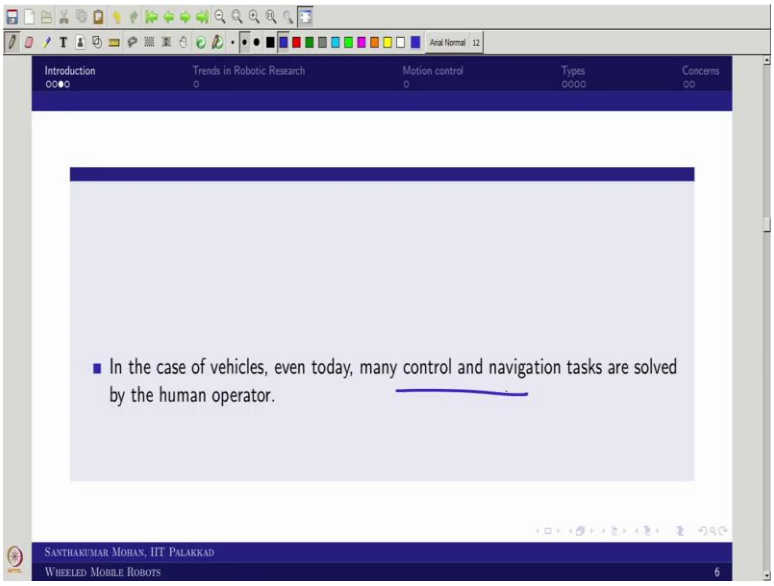

So, now in that case what you can see that the control and navigation is actually like very complex task, most of the cases we are trying to solve with a human operator. For example, you take a mobile robot in industry warehouse so that mobile robot would be controlled by some of the stuff or staff who is actually like sitting in a control room and giving a commands, ok.

So, in that sense what you are seeing that the control and the navigational task we are trying to you can say solvable with the help of human operator.

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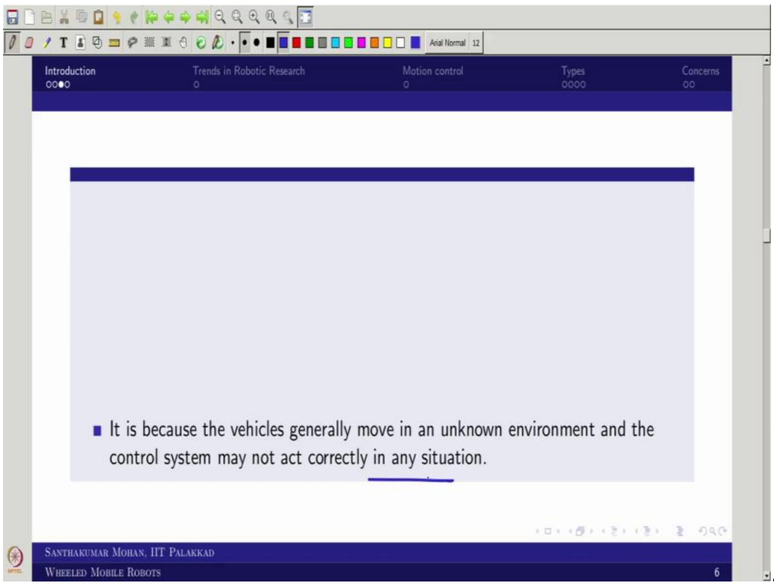

Then what is the biggest challenge? You see that the vehicle is actually like generally moving in a unknown environment. So, that is why we are deploying the you call human operator, but the human operator would be end up with some kind of fatigue and other things. So, then you have to see what the trends have come so far.

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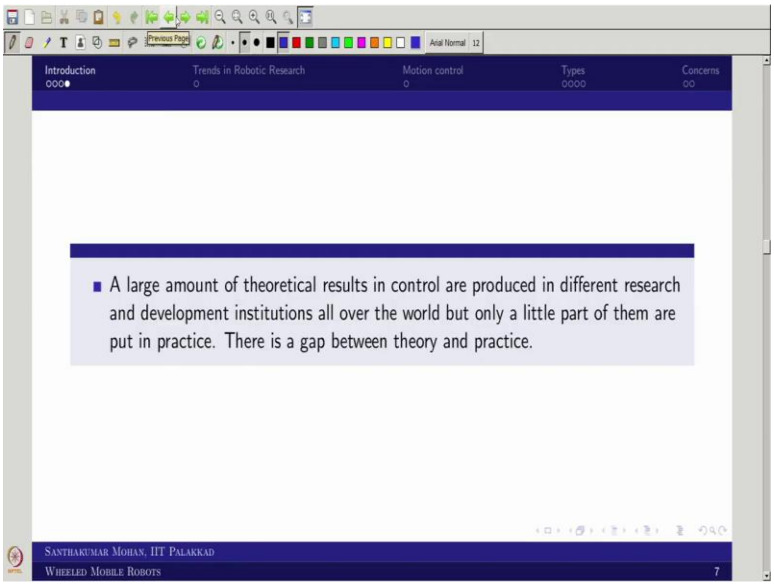

So, before going to the trend, so I am just giving a small you call warning or I am saying the small note. Even you just Google it in you can say in Google it as a robot control today, you can see at least one or two paper which was published in probably one of the popular journal in a week of time. So, then if you look at it probably 1000s of 1000s papers have actually like come in robot motion control, why it is so? So, why it is actually like happening?

For example you take the vehicle configuration it is more or less actually like saturated. Whereas, the robot motion control is actually like keep on evolving. So, some small changes then still people are able to get a you call control journal paper why it is so? So, there is a small you can say issue, the real time implementation required lots of lots of you can say further ends. So, that is what we are going to discuss in this entire week.

But before that what one can see? So, one thing you have to see the real time is completely different and what we are doing in a computational environment is different. For example, now I did in a MATLAB simulation I can make a close loop simulation very easily, I can give a exact profile following but in reality it is not so.

Why? The controller would be having some latency and you are talking about autonomous and you are talking about sensor integration there are several challenges. So, that is why you can see that there is a big gap always exist between the theory and practice at least in robot motion control.

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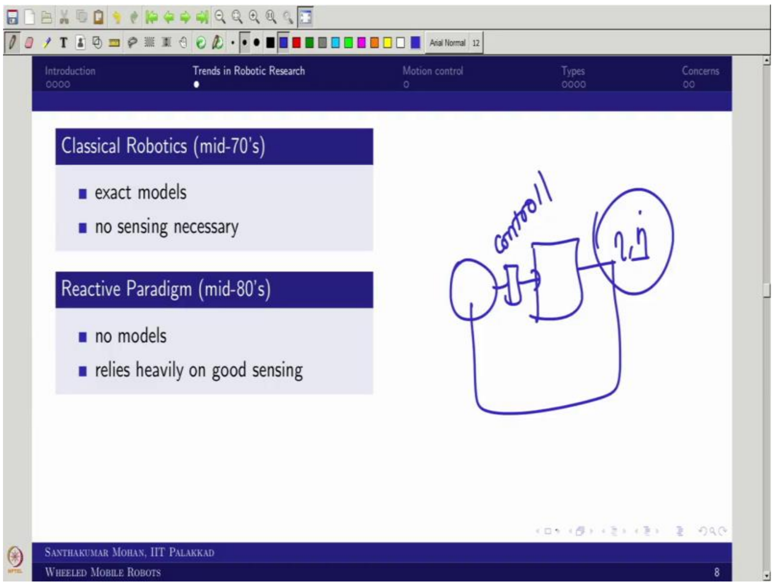

So, in that sense you just recall the trends how actually like we are going across. So, when we talk about the initial stage of robotics which we call classical days of robotics, where the people are actually like purely depend on what so called the model. In the sense when I fabricate anything I assume that everything is exactly known to me and over a period if it is wear and tear comes, so then this particular system will not work.

Why? The classical robot are actually like depend on exact model and no sensing provided. In the sense in the classical robotics all pre programmed systems or pre programmed machines, which is nothing but mechanized machines not as a robot as such in the current domain. Then what happened later on? In mid 80s, so people actually like brought very popular controller.

For example, 3 term controller and other you can say controlled strategies all came which was actually like closed loop, then people brought that particular domain what we called reactive paradigm where then immediately people move out. So, they imagine that ok this exact model is not going to work, because the wear and tear or probably over a year the system is actually like no longer exact model then you have to actually like play something else.

Then what people brought? So, they brought only like you can say sensing mode, in the sense no models used only actually like good sensing is actually like incorporated. In the sense everything is a feedback control in simple sense we call it is all motion base control. So, you have actually like your robot your motion which is actually q or eta. So, I will just put it, so what you call? So, your eta and eta dot you take as a feedback and you process it and you supply that as a controller.

So, in the sense it is actually like purely based on motion, but this is also like not working. For example, at least in mobile robot, why it is so, we will see. So, if you talk about robotic system the robotic system will have 3 stage; so one stage where the higher level where the people would be giving a mission level. For example, I said this particular robot designed for so and so purpose.

This is all what we call higher level commands which is actually like mostly descriptive. What the other two levels are important? One is system level then the system level is operate with help of actuators. So, then what you call, the lower level is actuator control. Whereas, this reactive paradigm was working in a actuator level very good and what you call the classical robotics was working very well in the system level. So, then people thought why cannot we combine this.

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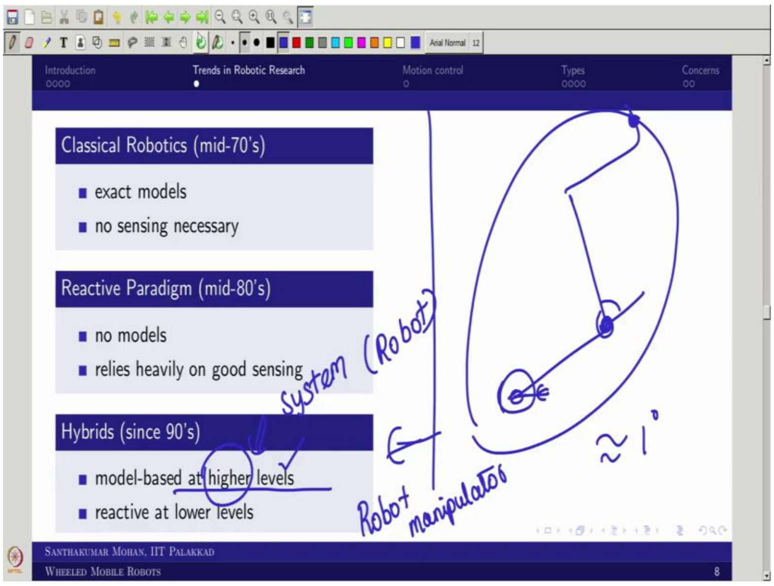

So, then what they brought as a hybrid control, where they brought very simple aspect the higher level what you call the system level, so here this higher level in the sense system. So, system in the sense robot level. So, the robot level you apply as a model base, whereas the lower level where you call the actuator level you use simple motion base like PI or PID control and all Proportional Integral, Proportional Integral Derivative all those controller. Why it is so? So that is very big question right.

So, I already said so if it is a system level, for example you take a simple reactive paradigm I am taking a simple serial manipulator for the example. So, this actuator is controlled based on the reactive paradigm. So now, this is giving a probably error of probably 1 degree, but this 1 degree is actually like propagated here right. So, you have a series of body. What happened? This reactive paradigm may not be corrected all the sense.

In the sense what mostly the robotician will do? A independent you call reactive control. So, in that sense what one can see? If you see this in the model level you know this is actually like my task base, this task base control I do in a higher level and the lower level were actuator level, so that work well ok.

So, then what the other side has seen? So, these all was working in one particular sector of robots. In the sense so, robot manipulator area were actually like happy about these combination which we call the hybrid control was ok for robot manipulator cases, but whereas the mobile manipulator or mobile robot these are not helpful.

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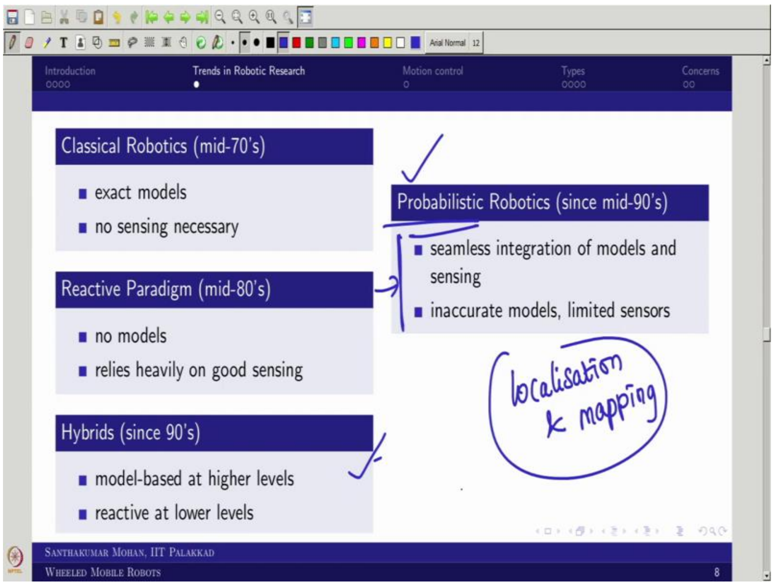

Why it is so? Because, the mobile robot is purely depending on the sensing and localization, in the sense lots of things are coming from the integration and you call environment. So, in the sense what one easiest thing is? People thought about can we apply a probability theory. So, that time the computers also like very popular and very modern then the probabilistic robotics have come. What they have done?

So, they have actually like integrated both model and sensing, what that mean? They have integrated model and sensing seamlessly. So, you have a primitive model and you have actually like you can say some kind of sensor. So, then I can integrate and I can actually like brought it.

So now, in that case what one can see? The inaccurate model and you call actually like less you call state variable, in the sense you can say limited availability of your state variable. Still both are actually like allowable, because you are going to use a probability theory where you are going to estimate your system response and your system states.

So, in the sense what happens? This probability theory is actually like very popular and manipulated theory is actually like required only small sensing and more on task level that was working with hybrid. But, here actually like what we do? First we will do the localization ok, so, in the sense so the localization and mapping.

So, based on this you do the motion control. So, that is why we are using the probability theory where we use several filters, we filter means nothing but estimator or predictor that was working.

Still this is also like one popular even now in mobile robot, but what happened in the recent past? So, that the data driven systems have come where you have primitive experimental result where what you are given as a input, what was your system response then you can actually like make a data driven.

So, even the data driven was there in olden days is in the form of knowledge base what they call? Neuron network, but this neuron network further improved based on the learning techniques.

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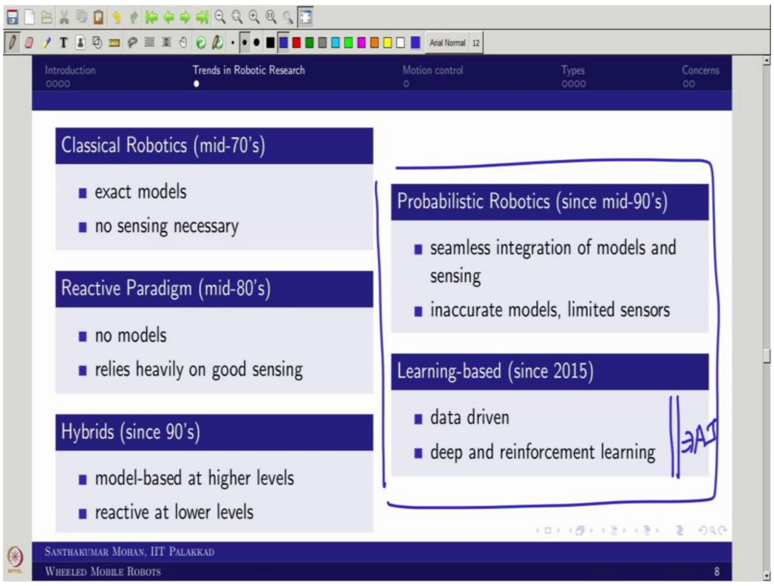

So, that is what we are calling learning base where the reinforcement or deep learning was actually like incorporated, in the sense what you can bring? So, you can bring it some kind of AI technique and you can bring some kind of intelligent.

So, in the sense what one can see? In the modern robotics is actually like modern mobile robotics actually like playing these two subsection but before going to these two subsection we will talk about only locomotion aspect and then we will see.

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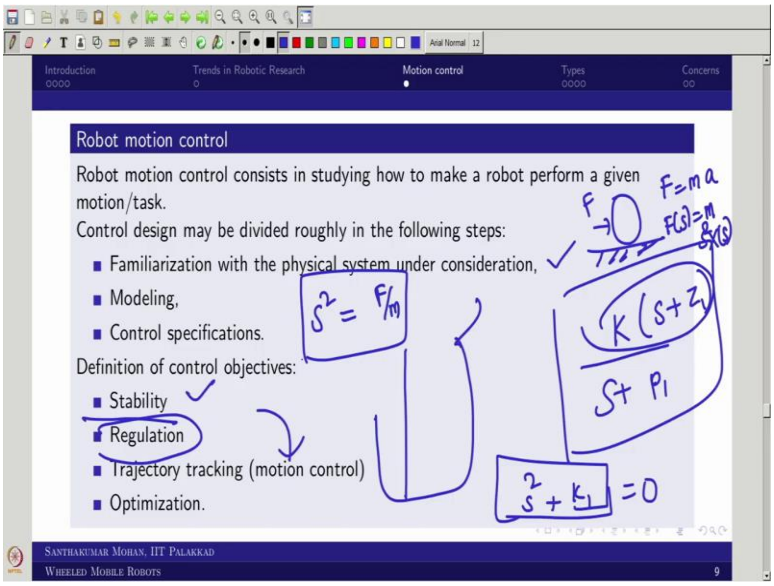

If you talk about only locomotion aspect then what you are thinking about? You are thinking about only motion control with a predefined way. So, if that is the case what would be the you can say steps we think about in a control design. So, you will think about when I am talking about control. So, what I will see, first I need to familiarize the environment right where to what to all those things, then I will see whether my system is stable right after that only I will actually like think about the performance specification.

So, in that sense what I will see? First I will familiarize then I will model that and then I will actually like see what is my desired thing. So, if I try to fulfill this what are the sub task will come? The sub task would be as objective. So, the stability is the prime most then I will actually think about regulation in the sense I will give a step input like point to point, whether it is actually like regulating or not. Then I will go to the motion control once these all achieved then I will try to optimize my resources.

So, in the sense what you can see? I will first familiarize, then I will actually like model and go to the objective or specification that specification will come in these 4 stages. But when you talk about the mobile robot the stability is one of the important thing, the open loop system always actually like unstable. So, in the sense the closed loop systems supposed to be stable, so for that you have to bring some of the aspect.

So, one of the easiest aspect is you bring some kind of damper in the sense you bring if you talk about classical control you bring a zeros and then you bring the poles, then you can actually like make the system stable right. So, that is what we are actually like trying to bring. So for example, I say that this is $\frac{k}{s}$ plus something ok. So, P so now I am actually like bringing some you can say proportional integral control that I can write as this right.

So, this is the open loop control open loop system, now I make it closed loop what happen? This $k \times s + 1$ as a part of what you call the closed loop holes, so then the close loop hole will actually like make the system stable. So, that is what we can actually like think about it and why the open loop system is unstable? You know like it is a second order system and mostly you will get this some k equal to or $k_1 = 0$.

If you think about the classical control most of the things very simple, you take a ball and put it in a you can say surface and you apply force F. So, what that $F = m \times a$ right.

So, you take in a Laplace transform this is $F(s) = M \times s^2(s)$. So, if I write this so you can see that $S^2 = \frac{F}{M}$ right. So, it is actually like unstable system right. So, that is what we are actually like looking at in the overall perspective.

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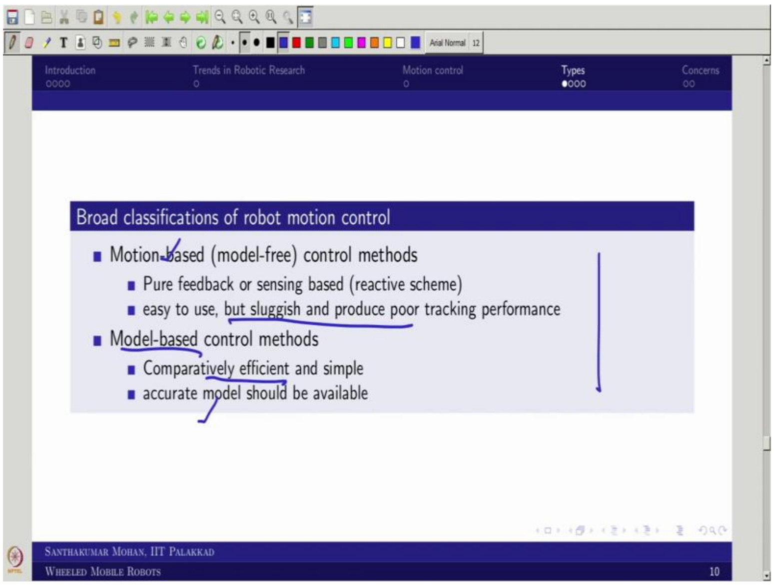

So, now we will move little ahead. So, what are the types we can think about in the motion control? So, one of the major classification based on so what you are actually like going to give. So, whether you are trying to make only a feedback or you are taking your model. So, in the sense what you can say model free and model base.

So, the model free what usually be called as a motion base and the other one is what you call a model based control. So, this is what we are actually like seeing the model base and motion base. So, that is what we are actually like trying to see. The model base is actually like EC in several basis because this is actually like efficient as long you have a accurate model.

Whereas, the motion base is actually like very easy to implement, but what happened, this would be actually like end up with slow or poor tracking performance. So, this is the way we can actually like see and you can say in the coming lecture we will see the other types and then we will see one of the type in detail ok. So, what we have seen in this particular lecture?

We were talking about what is robot motion control, how this robot motion control can be you can say implemented in real time and how this robot motion control can be broadly classified based on what you call model. So, if you have a model in your hand and you use, then that is called model base and you are using purely without any model and you are purely depend on feedback, then you call motion base.

So, these are the two different cases we have seen and the further classification along with one specific example we will see in next case, next lecture. Until then see you bye.