Mechanics and Control of Robotic Manipulators
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Lecture – 36
Introduction to Robot Motion Control

Hi, welcome back to mechanics and control of robotic manipulator. I hope you have actually like; come in one stage, where we have seen basically like the kinematics, then dynamics. Then we have seen like one step ahead where the trajectory we have generated that too like robotic manipulator. This particular lecture how we can actually like do the motion control.

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So, in that connection so we would be talking about a motion control in detail, in specific like we are going to talk about how to do you can say manipulator motion control.

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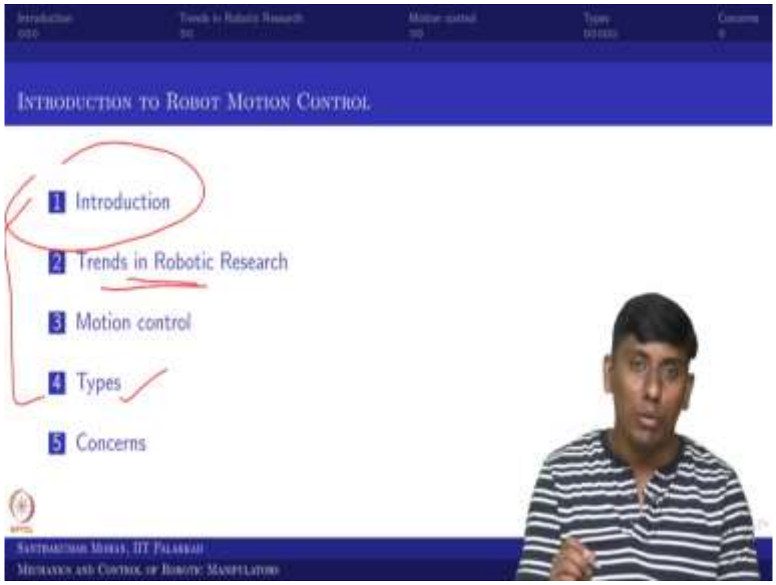

So, in that case we would be talking about you can say what is motion control, and what are the types of all those things. So, in that case these two are like more specific. While going across, so, we will see what are the trends were there in the robotic manipulator control, and what are the current concerns, which are related to what you call robot motion control.

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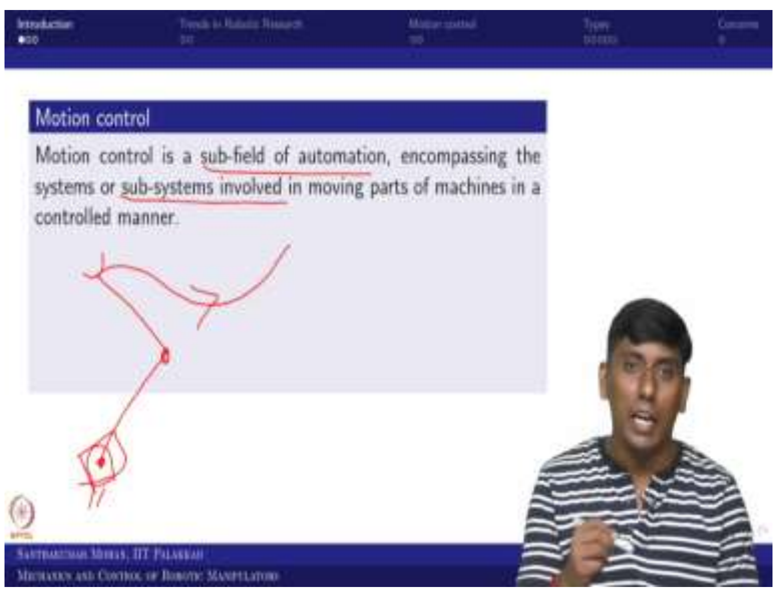

So, in that case first of all what is motion control? Motion control is a sub-field of automation. But what it is doing? It is encompassing the systems or sub-systems involved in moving parts of machines in a controlled manner. So, for example, I assume that this is the manipulator, which is having for example 2R serial manipulator which is fixed.

So, now I want to move this manipulator in this manner. In the sense what we are trying to do? So, we are making the system to follow the given profile, in the sense the moving parts of the system follow in a controlled manner. So, that is what we are calling a motion control; so, we will see in detail when it comes in real.

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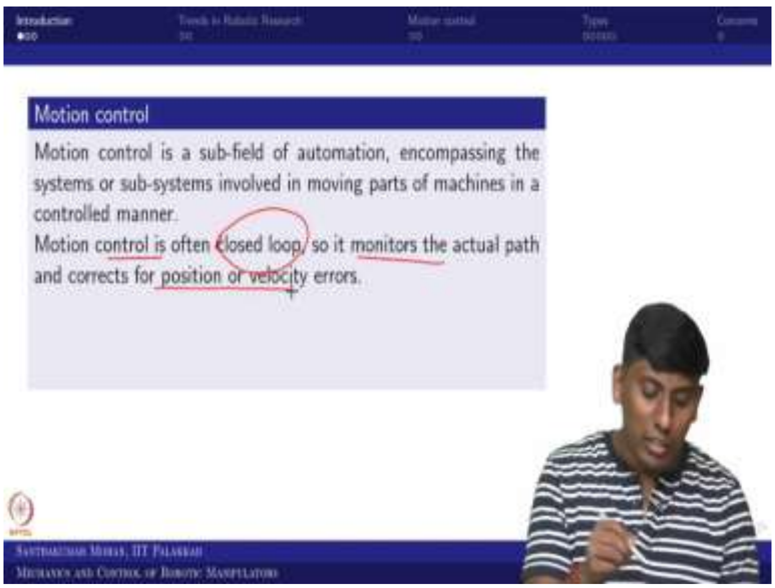

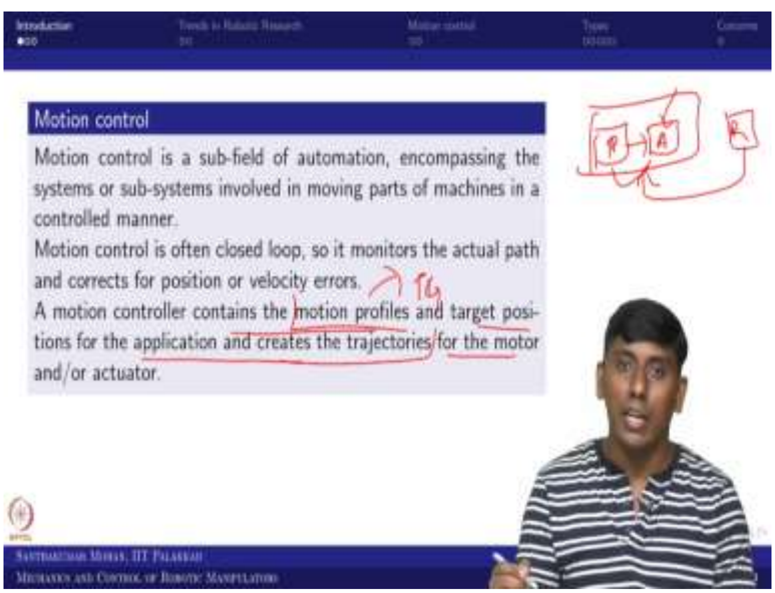

So, before that will just give, so motion control definitely closed loop; certain extent it can be an open loop. So, where for example, forward differential kinematics we have seen. So, the opposite what we have seen is an inverse differential kinematics which is controlling the manipulator. Similarly, inverse dynamics also we have seen; it is controlling the manipulator. But what we said it is a open loop, or we call feed forward control; so, that is why the motion control more often closed loop.

However, certain extent, for example, in the initial phase of the robotic system; so the systems are all like open loop control. So, in the sense we purely relay on the model, and we assume that the initial conditions are same; then we are trying to do it. So, in that sense what we are trying to do? We are trying to monitor the actual path of the end effector or joint motion and correct that according to the desired.

So, in that sense what we are trying to correct? We are trying to correct position and velocity. And accordingly, we would be correcting the torque or force; that is what we are trying to give. So, in that case the motion control contains the several things. So, one important thing is the motion profile which we have already seen in the trajectory generation.

So, we call simply TG, and the target position sometimes it is like a set-point control. So, then what we can see it is we have done up to this trajectory generation. So, now we are trying to see that how to control the motor or the actuator. So, in the sense if you talk about the control system; the control system would be having a trajectory planner and the actuating system.

So, which would be required some kind of control command, or probably some kind of relation between these two. So, obviously if it is an open loop, the trajectory planner to actuator directly will go. If it is like closed loop, so, you have a real robot, so the robot signal will be fedback to the control unit. Then that would be calculate the necessary control signal or you call actuator signal to compensate the system in such a way that the error would be close to 0, or almost 0.

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So, in that case first of all we will ask ourselves why we need actual control system. So, you know you can say the robotic manipulator or robot system. So, robot is not only a mechanical system, it involves or it fuses what you call controller. So, in that case, simple optimal design or optimal mechanical design so is not sufficient; because once the architecture chosen, what we will try to do? The manipulator design we will do, which is nothing but the detail design of the manipulator. That definitely will do it; but that is not sufficient.

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Because, the mechanical architecture is not the only one which is impact the performance; the controller also like impact the performance. So, in that sense we have to try to see how to do the motion control or generally control. So, in that sense there is one additional burden also come; this is very similar to all engineering application. So, where the robotic manipulator mathematical model also very difficult to find or found.

So, in other way around, the system is working in real time; so, the external impact, we call external disturbances are inevitable. In addition to the robotic system is based on the real time system. So, real time system definitely there would be uncertainties; because for example now I am saying that the actuator supposed to provide 10 Newton meter.

But there may be a mechanical loss or probably some other losses, it may produce only nine Newton meter. Similarly, the link length geometrically it says that the 10 centimeters; but the manufacturing tolerance provide probably 10.1 or probably 9 point something. Similarly, that you can say the joint also maybe end up with some kind of clearance and all.

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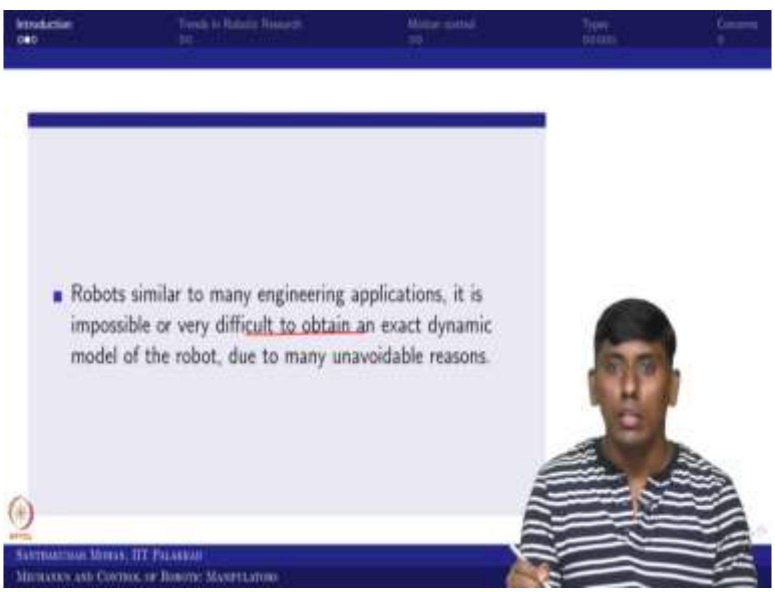

So, in that sense what one can see it is actually first of all very difficult to find the exact dynamic model; several unavoidable reasons, for example, the friction cannot be exactly model it. So, like that several difficulties are there.

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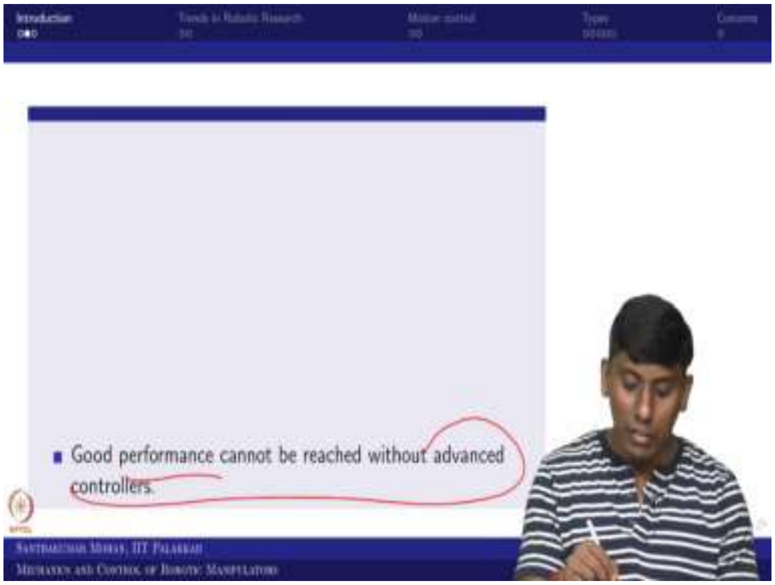

In addition to that what I said the external disturbance and the parameter variations are inevitable. For example, the manipulator you initially designed as a plain one; however, the manipulator is lifting some load which is unknown.

So, now what you can see that the parameter what you calculated based on the geometry would be differ, because the manipulator lift some pay load. So, in that sense you can see like these are like inevitable. In that case so like what we do with this kind of complex system; so, you need to have a advance controller. So, normal convention controller is not sufficient to do it.

So, in the sense if you need a good performance; so, the controller should be advanced. So, however in this particular lecture or in this particular course, we are trying to see how we can obtain this advanced controller through the conventional or probably regular practice.

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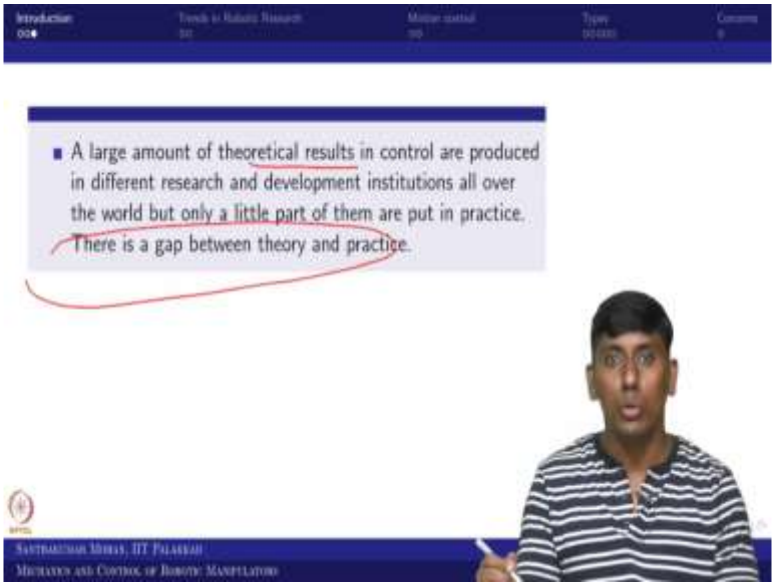

So, in that sense, so we would be asking ourselves so why we need to do several control research? So, there is one important aspect comes. So, here you can see that the theoretical results are like several; however, however what happened like the control is in real time implementation is very very difficult. So, although we can come up with very modern controller; but when we do it in real time in practice, so the controller what we implement in the sense, the hardware may not be capable of doing that; or the hardware probably expensive one; so, then we need to compromise.

So, in that sense there is a big gap between the real theory and the practice; so, here we are trying to address few of them. So, in that sense first of all we have to see how the trends, where there in the control aspect of robotic system. You know the robotic system started probably in early sixty, and seventy it is start getting some shape; and eighties, it is start matured.

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So, in that sense what mid-70 people have done? So, we call this is a classical robotics what they have done. So, they have considered whatever they build the manipulator or the robot; that robot is exact dynamic model of, or exact model is known. In the sense, all are like free, or you can say free from the feedback; and what we can call it is like pre-planned motion, everything is just like a mechanized.

And other way around, we can say everything is dependent on the open loop control. So, for example, I say that this is the ball; and there is pit, or some object is in front. So, I want exactly this ball supposed to stay here. I assume that the ball is going to pure roll, and I know the mass. And I calculate what the force required to stop; from starting 0 to here.

I make it as smooth profile. Then I can calculate this force, I continuously apply the force so that the system is stopped; I am not checking any feedback. So, then what we can see? This is purely based on the model. If the model is like small perturbation is there; this may not work. But, in earlier days, people are purely dependent on this, if this system is giving some kind of residue or error; they recalculate this rather than doing the feedback.

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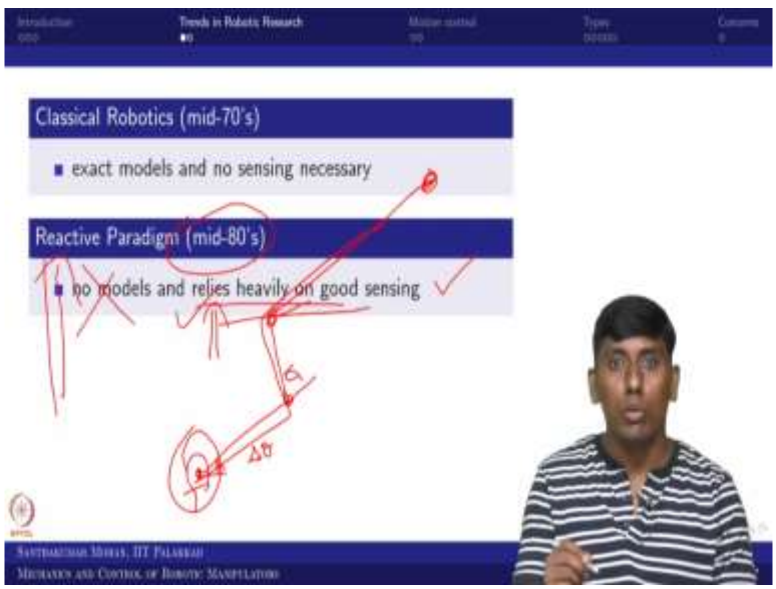

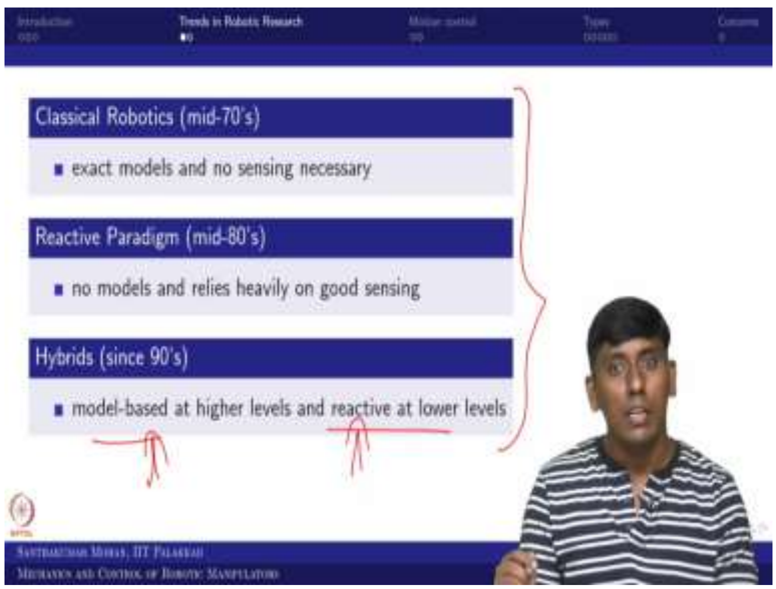

So, in that sense the exact models or no feedback are necessary. The exact model is necessary, and no sensing is necessary for this particular system. So, exact model is required, and no sensing is necessary for this system. So, it was working good as long the system is no wear and tear, or probably no compliance and all.

However, so when there is a compliance; so I assume that this is vertical robot. So, it is simple rotary manipulator; but the rotary manipulator is like in vertical. So, what happened over a period this would be having a deflection. So, it is supposed to stay here; but due to this, it maybe come here. So, the sense what happened this exact model may not work as such. So, then people thought about it, so then this said why cannot we use a reactive mode.

In the sense we will, you can say deploy the feedback; and we will do purely feedback base. So, what happened? So, there is no model required; but it purely relies on the good sensing. If purely relies you can say, on the good sensing, so then there is a problem. For example, you have a serial manipulator; so, I am assuming that it is like 3R serial manipulator.

If this is having a small error which I call delta theta error; so, this delta theta would be propagate, when it goes one another end. So, at the end, the end effector would be completely drifted at certain extent. So, in that sense you can see like the reactive paradigm worked in the actuator level very good; but the system level it was not really beneficial.

So, then the mid mid-80 which was so popular; even that time the three-term control which we call the PID control. But very popular these all are likely good reputation happened those days. However, later on the robotic community people rely on that; this is purely dependent on the feedback. So, in that sense the motion-based control is not really good for performance over a period; or it is not giving the exact error compensation.

So, then people thought about why cannot we combine these two? So, where you can say system level; for example, I talk about the so manipulator level. So, here we go with the model base; so, and the actuator level I will go with reactive paradigm. So, in the sense you would be doing two levels; so low and the system level.

So, low level I call actuator; so, system level is like higher level. The higher system level would be based on the model; this was like based on the feedback. So, this was working very very good; so that what even now people are working in most of the manipulator community. So, in the sense it is model based at the higher level and reactive at the lower level.

In the sense actuator level, it would be motion based control, and the system level it is model based control. So, these are all work very happily in the robot manipulator system; but the robotic manipulator come in an autonomous mode; and people try to put it in probably unknown environment. For example, the picking object characteristic may not be knowing; for example, initially the manipulator all come with for a rigid body operation; or the body characteristics is purely known before an end.

But, now for example, warehouse automation, where the several objects come in rack or in a conveyor. And you need to put it in proper you can say you can say rack of the container. So, then it is very very tricky, because the system supposed to work. And where the object is located, these also need to be work it on. So, then people thought about this unstructured and unplanned activity; so, they depend on something called the probability. And in you can say mid, you call 2000 onwards; the computer has come up with a very very bigger sense. So, then they thought the probabilistic robotics would be one additional benefit.

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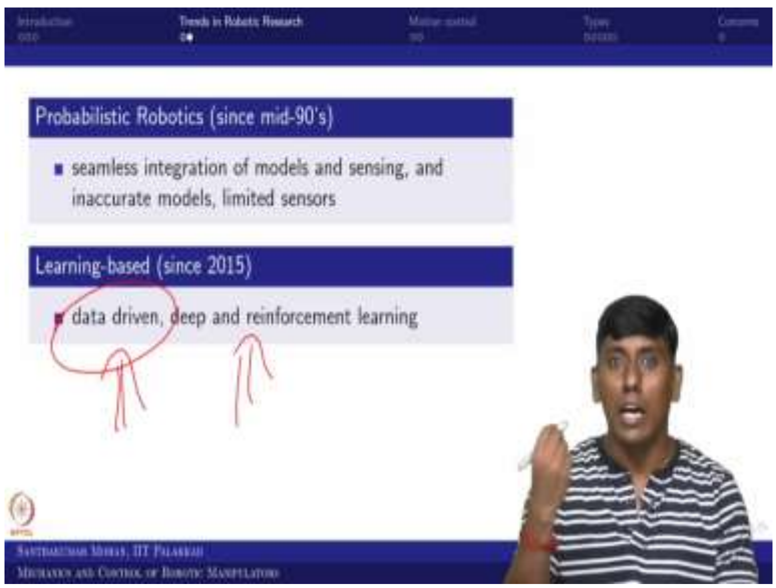

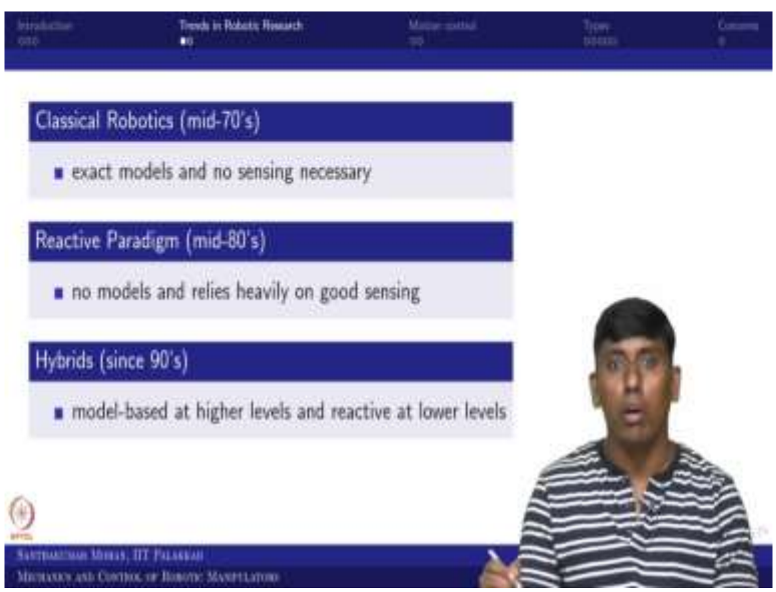

So, then mid- 90 itself people try to attempt this; so, where they said that seamlessly integrating you call model as well as limited sensing. So, based on that we can make very good robotic manipulator control; so, these all are like required additional computational complexity. However, this was working for autonomous mode or for unknown environment, where we need to deploy these kinds of manipulators, people tried the probabilistic robot.

Mainly, the probabilistic robotics have come for the mobile robot community; however, this was even used for the robotic manipulator, where some certain extent the autonomous or intelligent operation required. Even in that case in the modern days, so we know like the neural network I come up with very very drastic manner into all the field.

So, the same was attempted even nineties or probably two thousand, however, that time the computational capabilities were very limited. If you are deploying the neural network, the training is required, and you need to have a database which is supposed to be very heavy. In the modern days the data driven models have come which is regression based or learning based.

So, which was actually change the entire robotic community including manipulator, which brought the learning-based control. So, the learning-based control either it is a reinforcement learning or deep learning; however this is like purely depend on data driven model. So, this is what one deep insight. So, this is mainly dependent on if you are thinking about autonomous, or you are thinking about some kind of intelligent manipulation; then definitely we can go with this.

However, the conventional side, you can still limit with what you call the hybrid; or even certain extent if the manipulator is working very very slow in speed. And the structure is certain extent is well described; then we can go with the still reactive paradigm. For example, even you take in the modern days, even you order it probably KUKA or FANUC; so, the robot would be having a PID control or PD control. So, why it is so you should actually like know. In that case we will see what is the classification of motion control?

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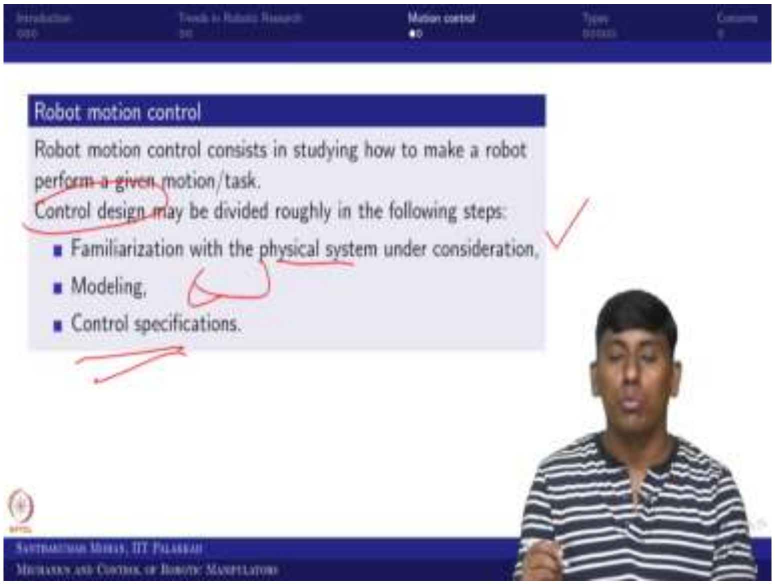

So, in that sense the robot motion control consists of several task in built. But before doing that you should familiarize the environment or familiarize about the task. So, so you should know what you want to do it with the manipulator and what is your system; then you can make the control specification. What you want to do it, in the sense you can come up with an objective.

So, so if you think about a control design; first you are like to understand the model. So, understand the physical system and then you can come up with a proper model. Then you can define your exact need. So, what would be the exact need?

So, one important thing is so you are closed loop system supposed to be stable. Then your error should be within the design limit. So, in addition to that you may end up with some kind of optimization, because your control input maybe required to be as minimum as possible you want to do it; or you want to make it the fastness to the system, so, optimality will come.

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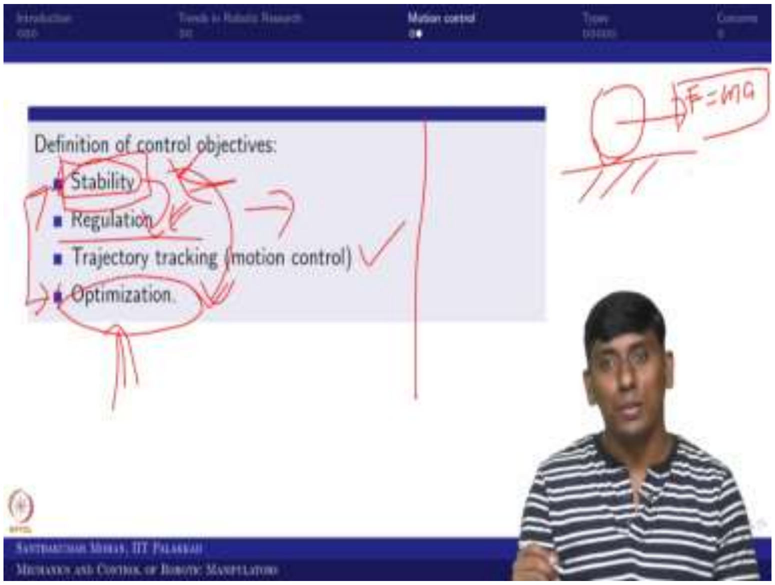

So, if you think about the control objective; one important thing is like the stability. The stability and regulation you can bring it very close to that; so, this is like set point, and this is like the decide input is like time varying. But most we will be trying to do this the system is supposed to be stable, and you are to do the optimization. So, here we will try to increase your efficiency of the system, or you can say decrease or minimize the resources.

So, in that case so we are bothering this; one important aspect I have already said the stability. So, the open loop robotic system that too like the dynamic system is unstable. For example, you take a simple mass which is rotating, you assuming that there is no friction. So, how we can model it this? So, F equal to ma.

So, you can see that this is second order system is giving an unstable nature. So, the similar way we can see even the robotic manipulator is what you call; it is something like unstable. So, the first thing is your closed loop systems would make it stable; and you can try to do the optimization and all. So, we have seen what is motion control and what are the trends have come in the case of robotic manipulator control; and we have seen what are the basic idea for the control design.

In that so there are four control objectives; in that one of the objectives is very important, which is nothing but the stability. And once you attained, then based on the given task, either it would be a regulatory task or the tracking task. The regulatory task people call it is something like stabilization problem, where the trajectory tracking people call the servo problem; or they call tracking problem.

So, either way we can say even some people simply call motion control means tracking problem. So, the next lecture we will see what are the types in the motion control; and then we will move to the one basic idea of the robot manipulator control. And will see some examples in numerical case. With that I am ending this; so, the next class would be talking about types of motion control. See you then thank you.