Design of Mechatronic Systems
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Lecture 31
Selection of Sensors and Actuators - Part I

So, we will start with this important aspect of mechatronic systems which is Selection of Sensors and Actuators. We have done the modeling so far. So, we need to use this model to now get to some of these estimation of sensor parameters or sensor specifications that we need to get to and actuator specifications. So, we will see some relationship and some interesting ways of computing the sensor or computing or arriving at specification of sensors and actuators.

So, I will talk about a little bit more detail and since we may not have to do entire simulations to get to these, but we can do some kind of ballpark estimations of the parameters in some way. So, as we go along, we will talk.

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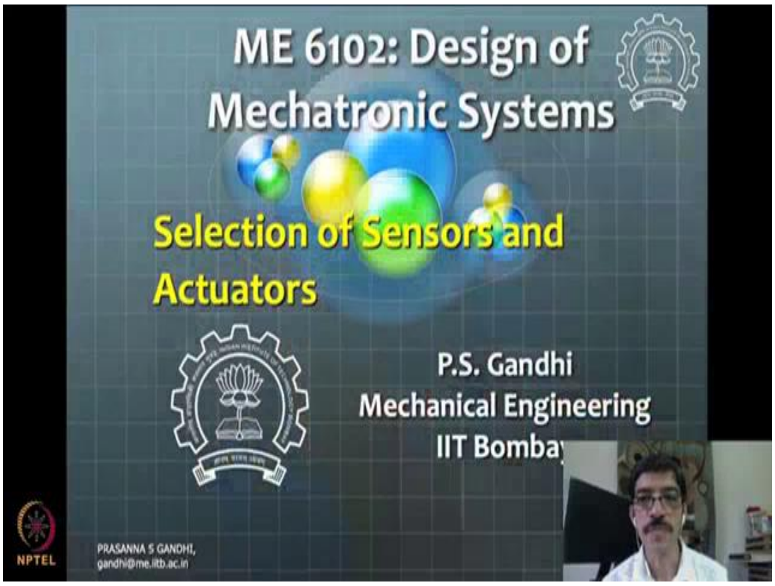

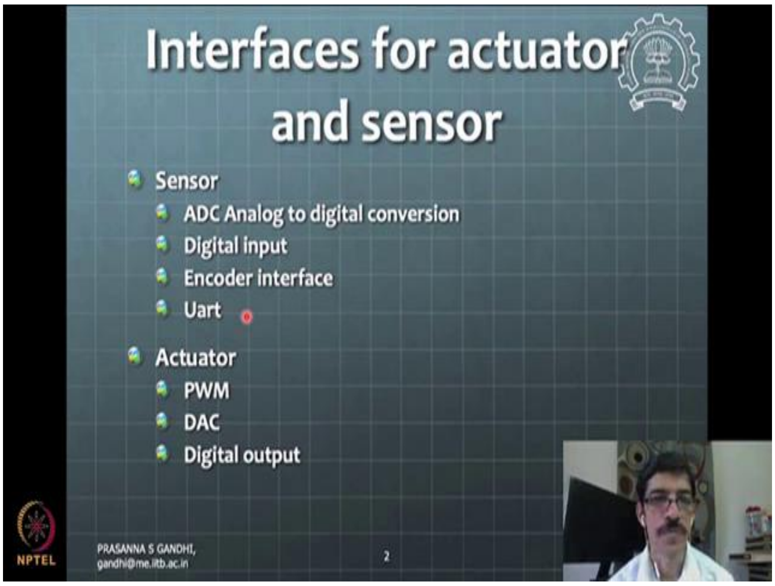

Now, we first bother about what are the interfaces for sensors and actuators and we have seen already a couple of interfaces, so PWM, you may have digital analog converter for actuator or say simple digital output for the actuators like solenoid. For sensors, you may have ADC analog to digital conversion interface that we are yet to see that in TIVA we may see at some point or you may take it up in the project.

Digital input outputs we have seen for sensor. Again, we can use that. And encoder interface as QEI interface we have program. And you may use Uart in some cases where the data from sensors is available in Uart kind of a form already processed and you get only the numbers in the microcontroller.

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What are the important considerations for development of this sensor actuator specifications is first whatever are the system requirements, like what is the requirement for your control application or mechatronics application that we need to know first or we need to kind of given abstract problem, we arrive at those requirements first, and then we move on to sensory requirements. So, we map them to the sensory requirements. And for this mapping we will need modeling for the system.

So, what we have seen, in different forms of models like Lagrangian formulation is one of the thing or Newtonian formulation, so whatever like these models that we are doing some mathematical development that can be used for this map. And in fact, that should be used for this map, because then we will be able to kind of very clearly get all the necessary specifications and we do not over design actuators or sensors. So, for that you need this kinematic dynamic analysis, to do that. Then other thing is like you need to make sure that about the noise considerations.

Now, system specifications will be in terms of some resolution of positioning that is required or resolution of some whatever output that is required and we need to make sure in the presence of noise we get in that kind of a requirement satisfied and a noise, so you need to see what is the noise in the environment around it and like what is to be done to suppress the noise and some kind of filtering that need, may need to be done. All those kinds of things are to be accounted for. We will dwell more about noise a little later actually. So, you need to keep this in mind when we develop the sensor specifications.

Then you can have a choice of analog versus digital. So, mostly, the recommendation is to go for digital sensors for making sure that noise consideration is not bothering too much, actually. And either of you do only in cases where like you do not have any option for the digital sensor. For example, strain gauge for to sense. You typically, will go for analog strain gauges. There is no digital output for the strain gauges. So, you use that and amplified output of that, then you need to kind of bother about some noise filtering and then use that data from ADC channel to convert.

Then you will need to, of course, match the interfaces and its compatibility in its interface specifications. For example, if you are using encoder interface and you have some range say 50, 60 mm and some resolution for encoder then you get a number of bits. So, that number of bits of the encoder channel should match the range requirement for you.

So, number of, numbers that are getting represented within that range, say 0 to 60 mm, I want to kind of go and I have a resolution of maybe 0.01 mm or like that is one encoder count or that is what if it is given, then one can estimate how many number of, numbers that will get represented from, going from, 0 to 60 mm and then correspondingly I would have a number of bits estimated and let us say that encoder channel must have a minimum these number of bits to kind of get the sensing done properly. So, that within that range, I do not have to have deal with this number overflow situation scenario.

Then, of course, use of filters I talked about for noise consideration. One has to do that. And then filter has another implication for increasing your sampling time, because the filter calculations have to happen within the sampling instance. So, again, those details we will talk a little more in the in the future. There is another thing, that you need to think about whether you want analog filter or digital domain filter to be done. Analog domain filter and, so this filter discussion we will be reserved for the future part.

When you go for digital domain filters, then only like you will have to do computations in microcontroller. In analog domain filter, you may not need to reserve a time in the sampling time for filter calculations. Then, of course, cost implications, and then you can do this mathematical modeling and do the preliminary simulations to get to the sensor requirements or actuator requirements.

And then, of course, one has to see the manufacturers' catalog to do the proper choices, because you may not find exactly all the specifications you have drawn, the sensors may not be available, but there will be some conservative like the, you will have some sensors which are beyond satisfying all the specifications and having some more kind of additional features we can go for that. So, we need to have this minimum estimation done and then choose something which is better than that. That you have, we choose from the manufacturers' catalog.

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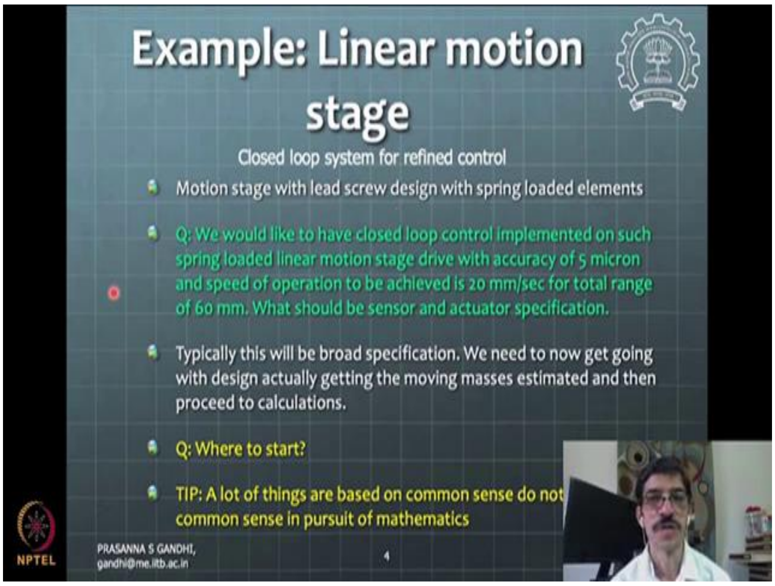

So, let us take an example of linear motion stage and then work about how do we get going for the specifications here. So, you have, say motor stage, we consider like lead screw configuration which with spring loaded elements for, so when we have such a kind of a system motion stage with a lead screw and we have given this problem. So, we would like to have this closed loop control implementation for such a stage such that drive accuracy is about 5 micron and speed of operation to be achieved is about 20 mm/ second and range is given to be 60 mm. So, what should the sensor and actuator specification.

This is like a typical problem that could be appearing. Some of the data may be given, some of the data may be missing and you need to kind of make assumption or make a reasonable assumption for the application that is required. So, this is now, we are given this already. So, this may not be in this form. Some people may be, look I want to use the stage for biological slide scanning purpose. Now, only this kind of specification given, you need to ask some more questions to the people, for whom you are kind of developing the stage and get to know like what are the more detailed specifications that they require in terms of design.

So, this design specifications arriving at is based on the, what is the requirement for a user of the application. Then we will need to get for more detailed kind of sensors specification. So, here, based on this data given one can kind of now come up with say, if I mount the sensor on my motor and then there is a lead screw, the lead screw will have some specifications of like, lead for when rotation is say 1 mm, 2 mm, some kind of a specification.

Then one can say, for motion of 5 micron I will need to have some kind of kinematics estimated to see how these 5 microns on the lead screw side or on the motion side like linear motion side translate to the rotary motion side, that you can do very easily by using some kind of a simple kinematics.

So, that kind of estimation needs to be done, so to get to actual sensor specifications. Then other thing like, for example, to get to actuator specifications one has to kind of do some kind of, think about some kind of dynamics. We will get to that. What are the moving masses in the system and anything with that? So, I will give you some kind of a broad outline of the process that can be followed. So, where to start? So, this again, all these things will be a little bit of a common sense if you keep it active like things will be falling in place.

So, how do we go about doing this, what do you think? Just think about like suppose you are given these specifications and now you want to get to the sensor and actuator specifications as we have seen like considering this lead screw one can kind of get to, little bit of kinematics. So, I will just give you some broad outline of the process that you will follow. I mean, this is a common sense. I mean, if you think there are some additional steps that can be done, it is all up to you.

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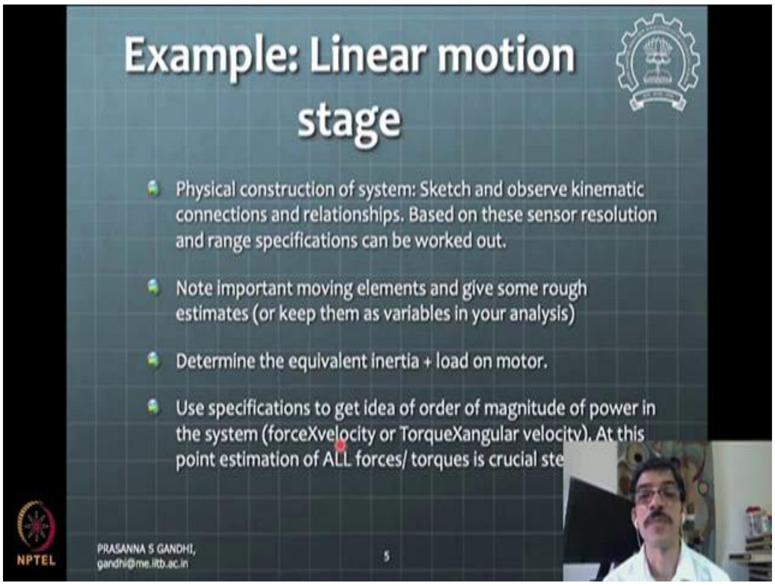

So, see first, like you can do this physical construction of system and sketch and observe like what are the kinematic connections and relationships. This is very simple for this linear motion stage, but it may get into a little bit more complexity for more complicated kind of problems.

So, we will see a similar kind of a thing one more example of 2-R manipulator to get to this kind of discussion.

So, then now you can get sensor resolution and range specification based on these kinematic relationships. As I said, for like given the specification 5 micron on x side motion, how much it translates to the rotary motion for the sensor. And typically, if 5 micron is a resolution and corresponding to that you have estimated resolution on the motor θ side, you need to be better than that from the digital control perspective, because, corresponding to 5 microns let us say it is some α angle on the motor side.

Now, if you select sensors which is exactly of this α distribution, then the problem is that like your control is happening every sampling instance and then there are many different kinds of other elements that are there, for example, some of the noise considerations. Noise in this case would it would be like, it is digital sensor if you select, then noise from the sensor may not be there, but there will be some kind of a friction in the system which will affect the positioning resolution. So, there are the errors that are there in the positioning that will happen based on some kind of dynamics of a system that need to get accounted for in that resolution.

So, we need a better resolution than α and it is typically like one-fourth or one-fifth of α that we can go for. So, it is very hard to get single count of, so when we say resolution is α, it is a single count of the sensor which is α. So, one count, within one count you get to the accuracy is very hard problem to solve from digital control perspective. So, you will maybe better off by solving up to two or three times, it is comfortable to solve. So, your resolution is α by 3 for the sensor and what you get after like control is α.

And why that happens, we can see some part in the simulation, see there are many different error inducing that happens around the different-different elements in the whole of the path of control. So, one of them is like say you can see the sensor quantization, quantization aspect will have some kind of effect on the dynamics. Like that, there are the noise I talked about, then the fiction I have talked about. So, from this perspective like you need a better kind of resolution, than your estimate of what is required from the given user specification and application specifications. So, this is an important point to note here.

And one has to kind of, see if you have to get to that exactly it is a hard problem. So, one can work with this ballpark kind of estimates that comes based on mainly kind of experience that you are able to kind of position within like three, two. So, when we are within say three to four times like the resolution of the sensor actually is there. So, that is why like your sensor resolution needs to be a little better than what you get by just these kinematic relationships estimate. And that, typical number is maybe three or four times better.

Then, you can note this other step that you will follow is like noting, like moving elements in the system and give some rough estimates of what is their mass and other stuff. Then, so then they can be kept as a peripherals, sometimes it depend upon like what is application that you are dealing with. Then you can determine the equivalent inertia or load, inertia and load on motor that is coming and then this will help to get the motor specifications done.

Now, the motor specifications would come not by like, you can, one way you can go about it simulate entire kind of process of whatever you want to achieve little bit cumbersome, but you can get simple ballpark estimates by using like this force into velocity of power relationships like, force into velocity or torque into angular velocity these kind of power relationships you can use. So, you can go directly like say you are given this linear stage, the force on the output side is estimated is a friction force and some inertial load force that is estimated to be some value and then you have some velocity, maximum velocity that is coming up in the system.

So, you can use maximum force and maximum velocity to get the conservative estimate of total power required by the system or one can kind of translate that into torque and angular velocity on the motor side and then do that. So, whenever you do power calculations, like you say you do say, power calculations on load side if you have done by this linear stage, for example, for this linear stage, then while translating to the motor side, one can use some kind of efficiency of power transmission so depending upon like friction. For example, in this case you have a spring-loaded element that is coming up here.

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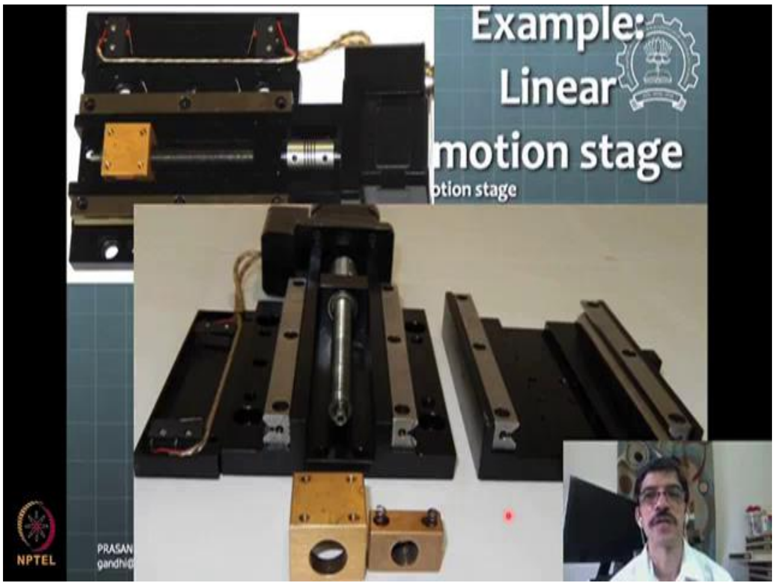

So, that is, you remember the stage assembly, you have the spring-loaded element which is loading onto the screw, so as to kind of prevent a backlash. Now, with this spring loading, your friction will be very high, in this case. So, your transmission efficiency will go down because of friction and you need to kind of account for that while building your actuator. So, right now, we are thinking of using some kind of a servo motor as the actuator in this case and this will start affecting the power required for the servo motor.

So, one can start with the estimates many times when you do not have actual kind of a thing and this design process or like this is little bit an iterative. You start off with getting some kind of details and then use those details to get to the manufacturer catalog to select a proper sensor. And once you select the sensor, you see other more details information and then see whether that will suffice what you have made a choice. And if it is not, then again iterate like next time to kind of see like other kind of specifications.

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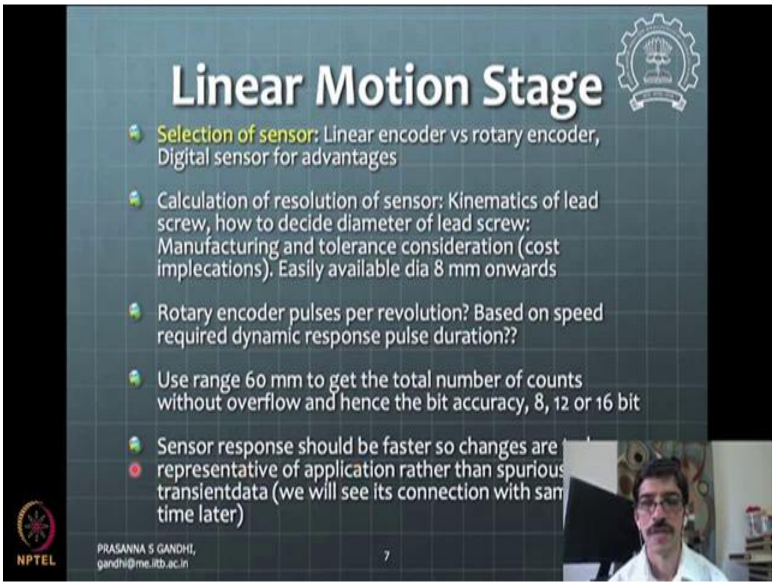

So, that is how the process will typically go on and this process you may probably need to use it in your project now. When you do not have like real choice in these sensors and actuators, we may do that, look I have estimated but I do not have. Whatever sensor I have, is this only because of the resource constraint. Then you can say how this, suppose you select that kind of a sensor, how it will translate to the resolution or accuracy that you will achieve for your final task, so that translation that we would like to see in your presentations and things like that.

So, we will select, for example, here for the linear encoder we will select for this. If you are really interested in the output side positioning and we know that there are some kind of backlash elements in the system which will affect linear to rotary part. But if we say, we do not have much of a backlash or backlash is taken care of by the spring loading, then rotary encoder can also be sufficient, because we know that there is no uncertainty between the input and output.

So, then, rotary encoder if you want to select then it will be much, what you say, coarser resolution than a linear encoder because there is some kind of a lead screw connection between the linear and rotary part. And, for the entire rotation of 360° on encoder side or motor side you will have a displacement only of 1 mm on say linear side. So, that is corresponding to the lead of the screw, and that is how like your requirement of coarser or like finer resolution will change based on where you are mounting the sensor.

So, you need to think what is the place that you are going to mount your sensor on, and according to that the resolutions have been change. And, one needs to be smart to choose this properly, so that not to harm the applications also and at the same time you do not increase the cost unnecessarily. So, that is how like this choice of mounting the sensor at appropriate place would have some kind of thinking required.

Then, as I said earlier, this we decide like diameter of the lead screw and lead of the lead screw now these all like the choice of the lead screw and sensor they are, now we can see that they are coupled here. So, once you choose the lead screw of particular thing, for the same application, the sensor requirements gets frozen or if you think, No I would want to have some kind of a better possibility that I do not want to use too costly sensor here. I want to have coarser sensor used and I can choose a lead screw which is having lesser lead than previous choice.

So, like that one can think about, and this is all I think the based on some kind of a simple common sense understanding of these concepts of kinematic relationships. And making use of them, to think and get to what we want finally to achieve. There will be these considerations of manufacturing and tolerances which will have some kind of a cost implications. So, we need to make sure that these tolerances on manufacturing are not like directly seen on the resolution that we want to achieve for the sensor.

Say, for example, if I want a 5-micron resolution in the motion, my manufacturing of the lead screw should have a better kind of a surface undulations than 5 microns. Otherwise, surface undulations will start moving, the stage there and then like I may not get a perfect linearity that that I would look, I am looking for. So, those kinds of considerations will be there in addition. But this is about the surface finish. So, surface finish would be, most of the times like better. But what happens is, many times as we do the operation, I mean, more and more you used the screw then like it will get more and more smooth and it may get better.

You might have seen your car, brand-new purchase car the piston and cylinder these tolerances are such that their friction is little higher. But as you kind of start using like a running the car, in first few months like they get automatically better by, little bit of wear that is happening there. So, rotary and this we talked about.

Now, based on the speed required, the dynamic response also is important to see. So, based on speed that is required, you will have a good dynamic response estimated, on the encoder side. So, say speed is given on the load side, say lead screw x speed we saw 20 mm per second what it translates to on the motor side. On the rotary side which is how many pulses per second are coming and we need to have sensor which can give you output which is resolving those pulses nicely.

So, if the sensor inside is such that, like the pulse has some kind of a finite rise time and like the fall time, you may not be able to kind of get those pulses nicely for a very extremely high speed. So, you may observe, that maybe we can see, you do not have oscilloscope to observe but we can try doing this experiment where we start running motor at pretty high speed and see that you will find your encoder may start giving some spurious data. The data may not be completely matching what is happening there. So, that kind of scenario would happen.

And at that time, if you kind of look at the signal into oscilloscope the pulses will not be very sharp like square pulse, but it may be more like halfway to rise and then again fall, because the rise time and fall times they are kind of start now merging without any flat on the complete rise may not happen there.

And then you will get a resolution, based on the resolution you get the regression and range, you will get a bit accuracy for the channel and then these dynamics, so there are some kinds of a dynamic consideration for the sensor, but they are typically not so stringent actually. Many times, sensors will be responding much faster than your application requirement, but application requirement especially if the speeds are very high.

Now, these are relative terms, very high you will get to know what is very high only after like my estimation of this and making calculation and seeing, these are the number of pulses coming in, say one revolution and that is why one per pulse time will be some something like that. And then you estimated pulse, per pulse time saying that, now my rise time and fall time if they add up to the pulse time, then you will find that encoder is now on the verge of getting worst kind of a scenario. So, that needs to kind of be given some consideration. But most sensors you will find that this requirement is not very stringent.