Advanced Aircraft Control Systems With MATLAB / Simulink

Prof. Dipak K. Giri

Department of Aerospace Engineering

Indian Institute of Technology Kanpur

Lecture 45

Chattering Reduction in Sliding Mode Control

Hello everyone, in today's lecture we will be discussing more details on sliding mode control, what we have done in the preliminary part, and what we covered in the last lecture. So from the last lecture, we have what we obtained: our system, the system we have

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = f + u \quad \dots Eq(1)$$

We have the control part of the design through sliding mode:

$$u = -kx_2 - \rho \, sgn(S) \quad \dots Eq(2)$$

We'll come up with the MATLAB code for this control, and we'll observe how the system propagates different states and also sliding variables. This is the MATLAB code for this system using sliding mode control. So here, we have the system dynamics. The figures here also show the control, the same control you have designed here. Here we have used k, but here you see the same structure. These are the figure commands, and we have the final control like this.

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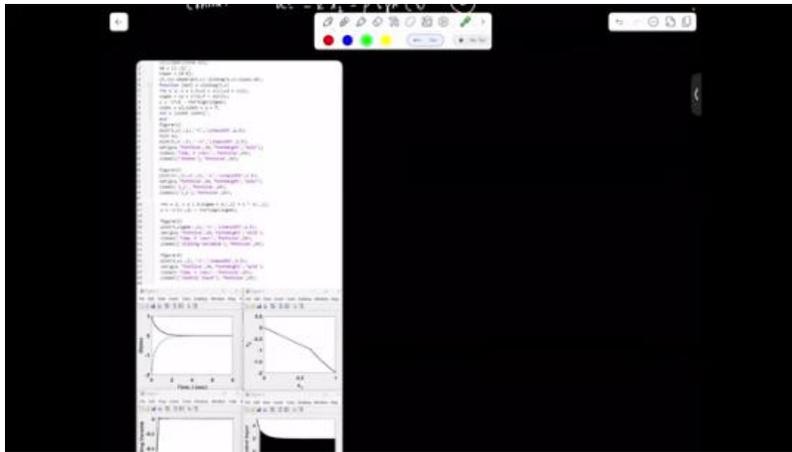
In these results, if you notice carefully, the states are reaching asymptotically to the origin, converging to the origin. This is the phase portrait, and this is the sliding variable, how it evolves over time. This is the plot for the control over time. Based on these results, we'll come up with a few observations that will be very important for understanding the sliding mode concept. Let me go step by step. Some notes: this is x_1 , x_2, this is the phase portrait. And this is the sliding variable. And this is the control. Right.

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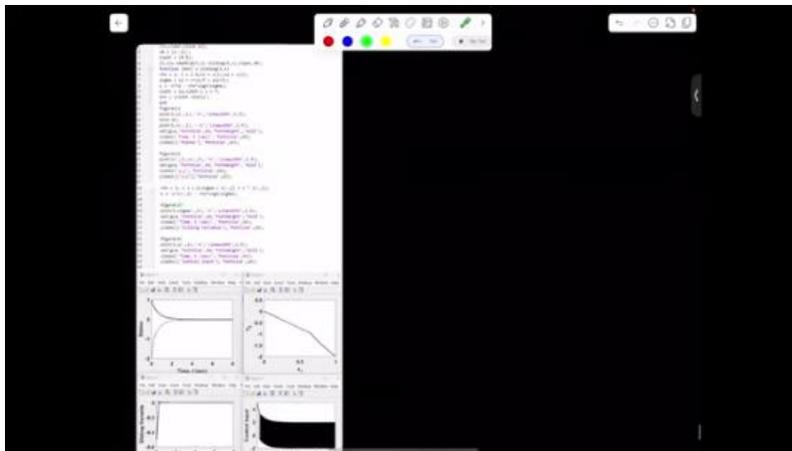
So here, the phase portrait from the phase portrait. The phase portrait. Clearly. demonstrates a reaching phase phenomenon where the straight trajectory is driven towards the sliding surface. If you notice carefully, this is the phase portrait. As time proceeds, the states go to the sliding surface, which is basically the origin. Right now, the sliding surface

and phase portrait phase portrait also also demonstrate sliding phase where the state stress trajectory is moving towards the origin along the sliding variable or sliding surface. This

is this two figure, the sliding variable and the phase portrait are fine. The critical issues are happening here. Though we are getting asymptotic convergence of X1, X2, but the problem arises in the control.

So the control, if you notice, we have chattering in the control. And due to this chattering, we have problem in actuators. So now the question is how to reduce this chattering. This is going to make a lot of issues for the actuators. For example, for the aircraft system, we have aileron rudder and elevators.

If you are having chattered control input to those control surfaces, there will be disturbance along the whole system. The system will be disturbed. so this is also sometimes called zigzag motion of the control so here basically we can see zigzag in control so now the question is how to tackle these issues before that i would like to write some note on how it is very problematic for the aircraft applications in many practical control system that is for example the aircraft control it is important to avoid control chattering by providing continuous or smooth control.

But this cannot be achieved because we are in the control algorithm what we are having. We are having the signum function. So now question is how we can avoid this chattering by providing some control or smooth control to the system. But if you assume some kind of function in place of this signum function, then it will not be no more sliding mode control. So we will take these things in this lecture.

a smooth control signal for instance for instance a learn a learn or we can write this part maybe we can remove For instance, aircraft control surfaces such as elevator, aileron, and rudder cannot be allowed to move back and forth because due to this problem this problem the control surface will be moving back and forth but this cannot be allowed practically with high frequency this is actually with its special high frequency this is moving this control surfaces but at the same time it is desirable to retain the robust place of the control system to bound it model uncertainties and external disturbances yeah so here uh to avoid this chattering problem we need to come up some smooth control law for these control surfaces for these control surfaces which will provide them a smooth basically robustness of the entire system so one such method we can apply is we have to modify the signum function so what you're going to do is the The switching control u_{sw}, what you have defined in the last lecture, switching control, basically

$$v = -\rho \, sgn\,(S)$$

you can write in the switching control, thus sgn is, can be, replaced by a sigmoid function which actually looks like

$$sgn(S) \approx \frac{S}{|S| + \varepsilon}$$

so here ε assumed to be small positive scalar so now if we take the limit of this function

$$\lim_{\varepsilon \to 0} \frac{S}{|S| + \varepsilon} = sgn(S)$$

So, we have to choose this ε very suitably to get the robustness of the system. And this problem, this chattering problem, can be resolved to some extent. So here, the value I should write here. The value of epsilon should be selected to trade off the requirement to maintain and ideal performance with that of ensuring a smooth control function. So, based on this addition of the sigmoid function, we can redefine our control, which is defined by equation 2. With the sigmoid function, equation 2 can be defined as

$$u = -kx_2 - \rho \frac{S}{|S| + \varepsilon} \quad ... Eq(3)$$

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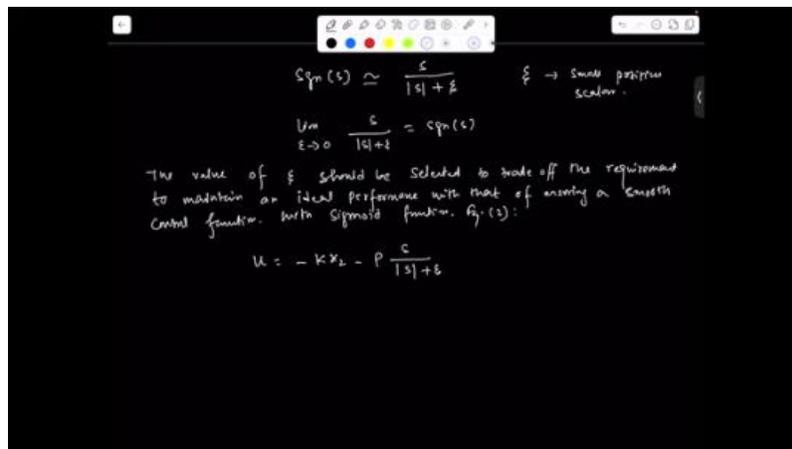
Now, let us see the MATLAB code for this redesigned control. So, if you notice here, let me fix the figure. Yeah. So, if you notice here, Even with the addition of this sigmoid function, we are getting asymptotic convergence in the states, and also the chattering problem in control is removed. But the problem we are having is with the starting variable, which is not reaching in finite time. But this problem is resolved now, so we can come up with some smoother here.
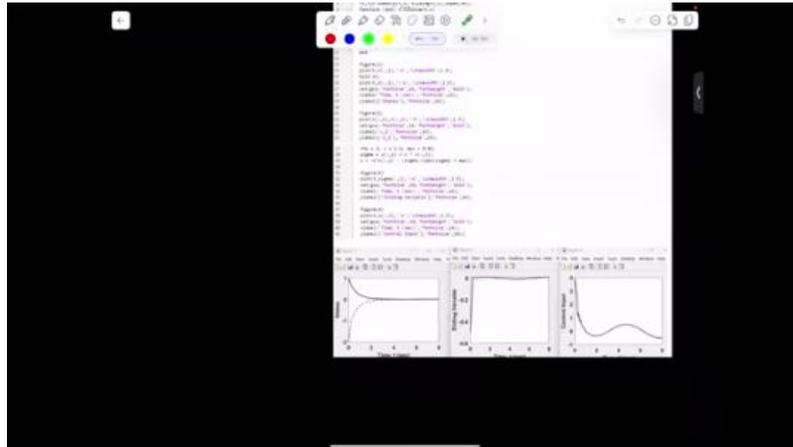
control input cannot provide cannot provide finite time convergence of the sliding 0 in the presence of presence of function f also a sliding variable at the state variable do not converge to 0 at all also because s is not going to converge in finite time so here this kind of control generally though this is not sliding more control okay let me write here a design control um in equation three in equation three it's not technically technically a sliding mode control since sliding variable has not been driven to zero in finite time right and however the the system the system performance

is acceptable since the states stays around the equilibrium point. And this kind of sliding mode, if you have, though this is not a final time convergence, and the app has been designed using sliding mode control, this is we call quasi sliding mode control. The sliding mode control, or we can write here, the equation three is referred to as refer to as quasi-sliding mode control so this is how we can come up the different type of sliding mode control so now we'll come up different structure of sliding mode control in the literature so using the uh this sigmoid function we reduce the chattering in the control but there are other methods also we can use to reduce the chattering so some of them are exponential reaching low you can use in the control so if you use if okay let me define it can be started exponential the reaching low based sliding mode control so here what we are doing is we are choosing

$$\dot{S} = -\varepsilon \, sgn(S) - KS$$

this k is actually giving the proportional rate okay control to the system so we can write here by adding by adding the term -KS, the state is forced forced to approach approach the switching manifold switching manifold actually is manifold which is basically sliding

variable s faster okay this is one structure another structure we can come up reaching law with power rate

$$\dot{S} = -K|S|^{\alpha} sgn(S)$$

where $K > 0$ and $1 > \alpha > 0$, So, these are the different types of $\dot{S}$ we can choose so that the control can be modified and chattering can be reduced in the control. So, these are the different observations in sliding mode control. Next lecture onwards, we'll discuss how we can design the sliding mode control for aircraft applications.

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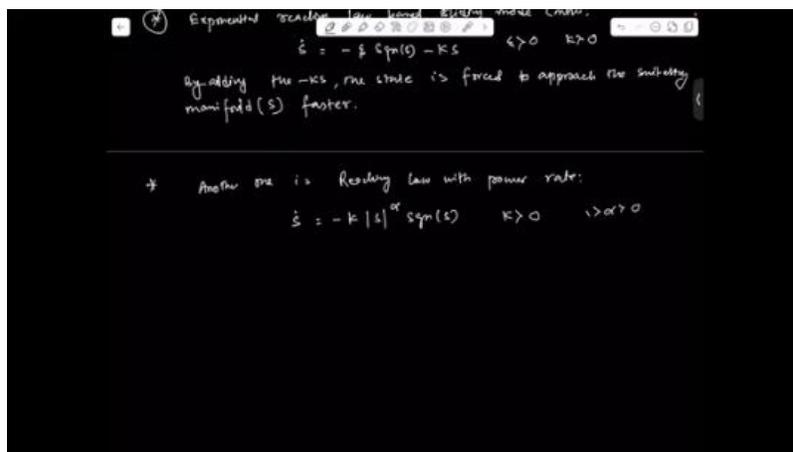
Then, I believe we'll have a strong base and understanding of the sliding mode control design for practical problems. Thank you.