Mechanic and Control of Robotic Manipulators
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Lecture No. 21
Velocity Propagation model using MATLAB

Welcome back to Mechanics and Control of Robotic Manipulator. The last class we have seen how to you can say generate Jacobian matrix and as well as how to obtain velocity for different joints starting from 0 to the end effector we call base to E, which we simply call velocity propagation model.

So, this is what we have seen and in the end of the lecture itself I said we will be seeing the same thing can be used in MATLAB as an efficient tool with a simple symbolic math code and we can see that in this particular lecture.

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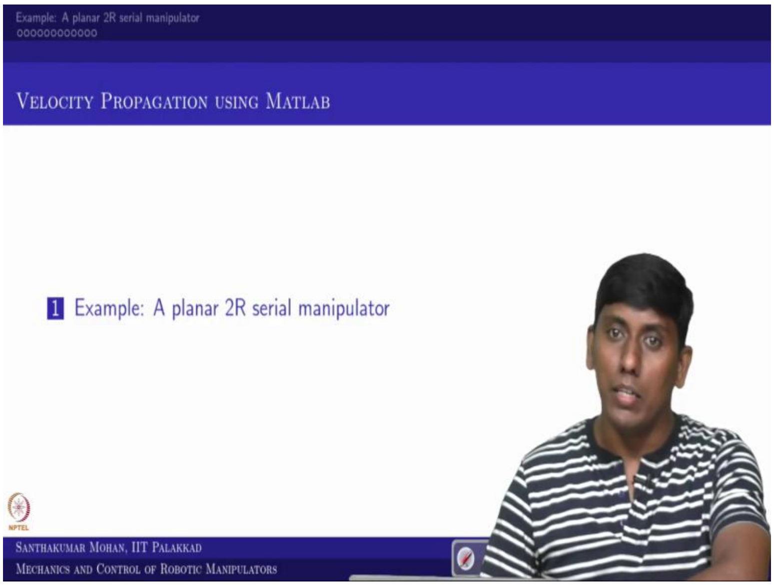

So, in that sense what we are trying to do is we will take the same example, which we have seen in the last lecture, the 2 R serial planar manipulator will take and then we will derive it that in MATLAB and see whether the same equation which we obtained in the analytical method we are getting into MATLAB or not.

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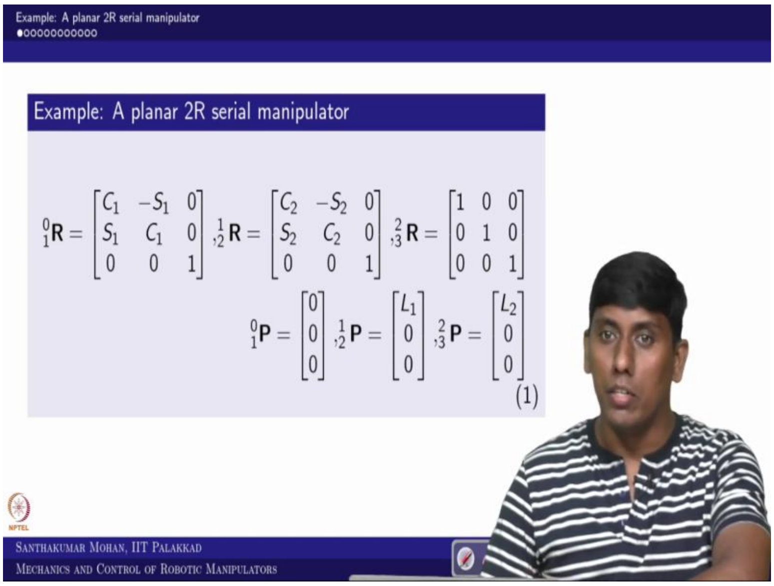

So, for that first we will recall. So, the 2 R serial manipulator is having 2 rotary joints. So, these are the; you can say rotation matrices and the position vectors.

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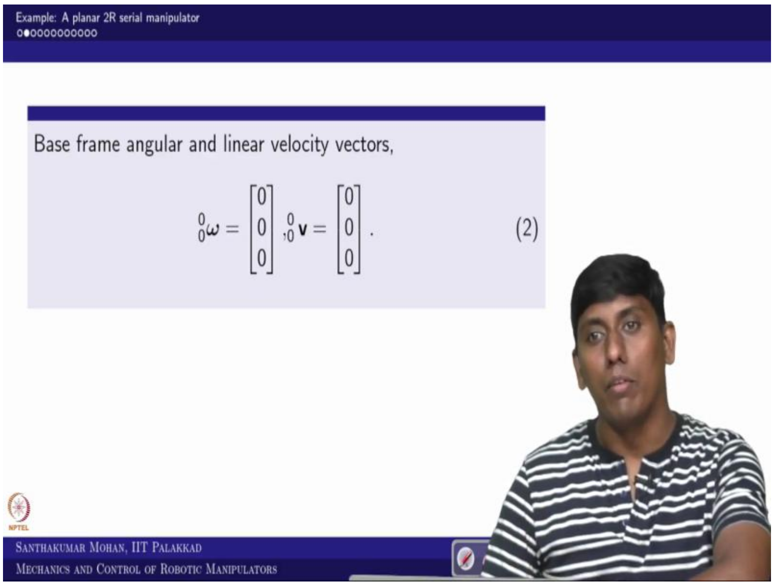

So, based on this if you take base velocities are 0, both you call angular velocity and as well as you call linear velocity, both are 0.

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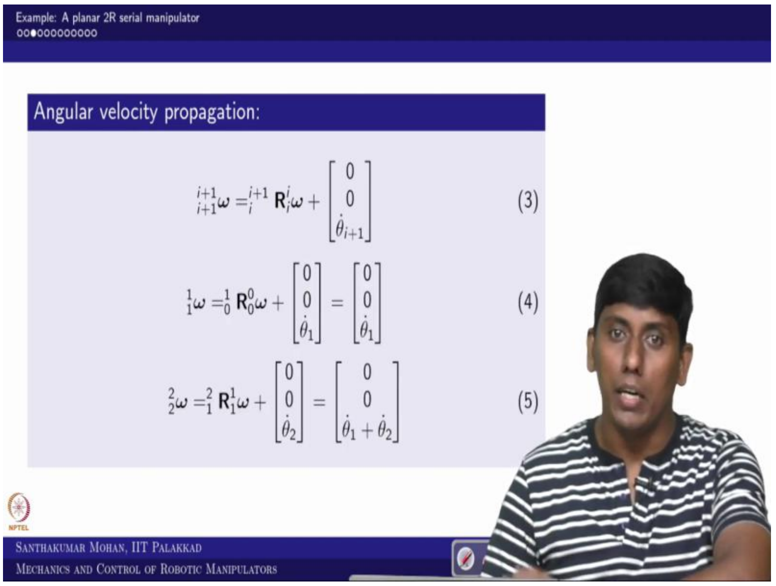

Then you can propagate the model based on the angular velocity propagation system.

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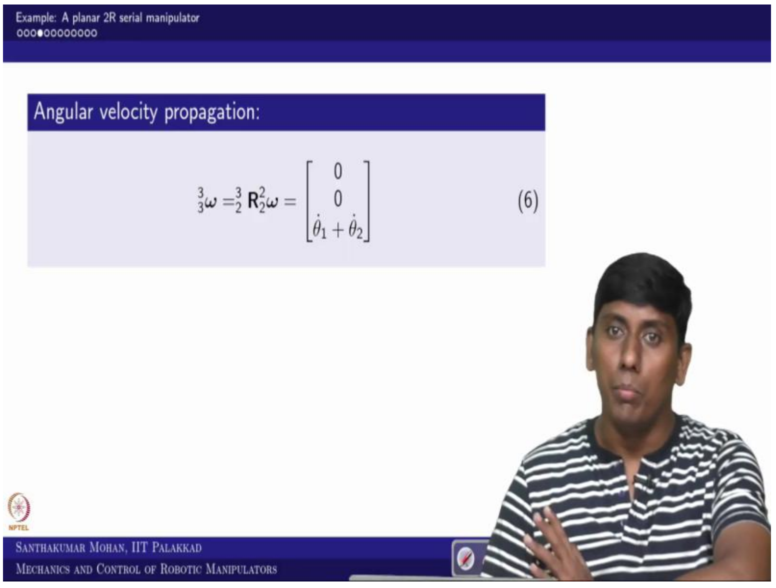

So, in that you can start omega 1 omega 2.

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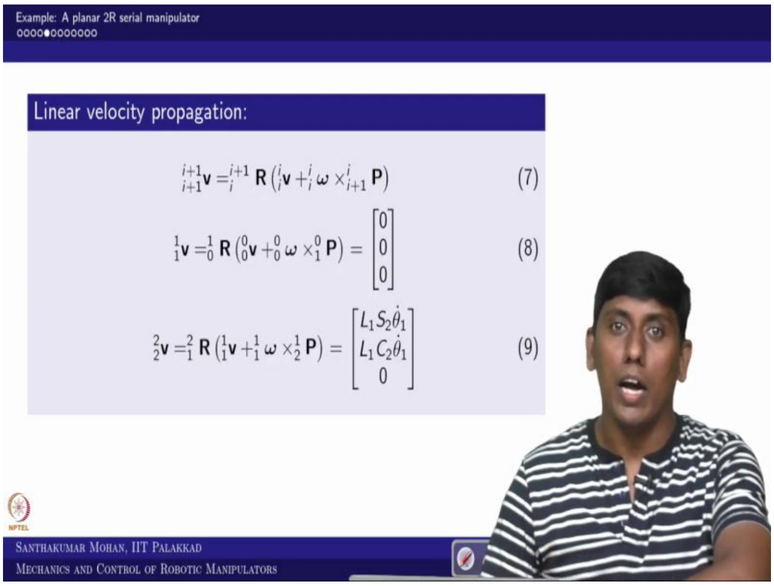

And then omega three. So, similar way we can start with a linear velocity propagation model and where we start from the linear base velocity is 0 and then we can propagate v 1, v 2 and v3.

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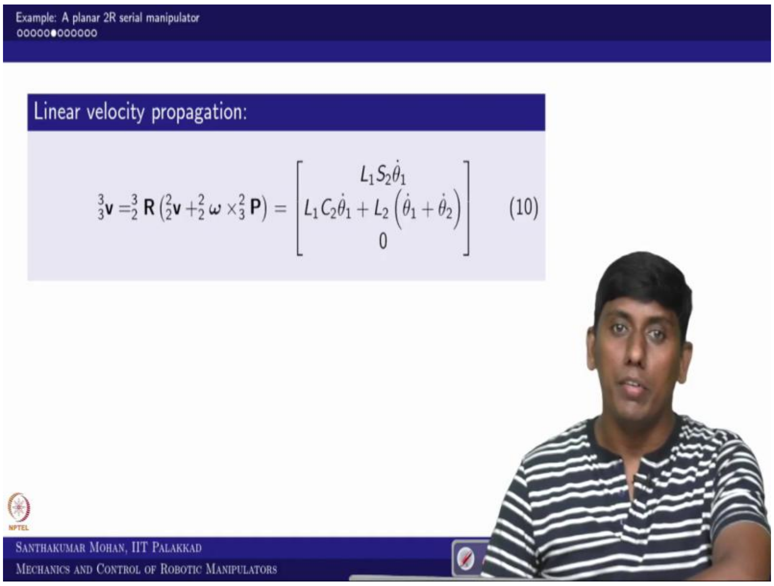

So, once we obtained we can see, we can get to the what you call end effector velocity with respect to you can say base frame, in the sense of velocity of 3 with respect to what you call zeroth frame.

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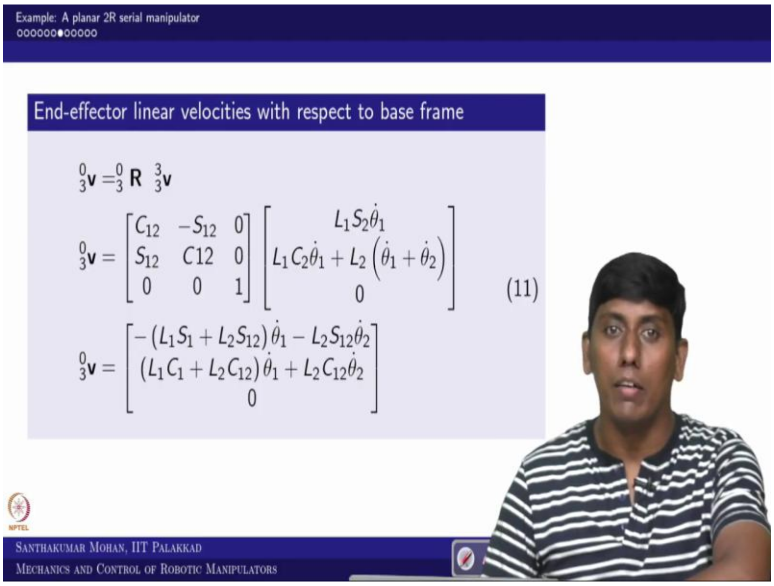

We can see it here. So, in that sense of what 1 can find, so this will give Jacobian matrix.

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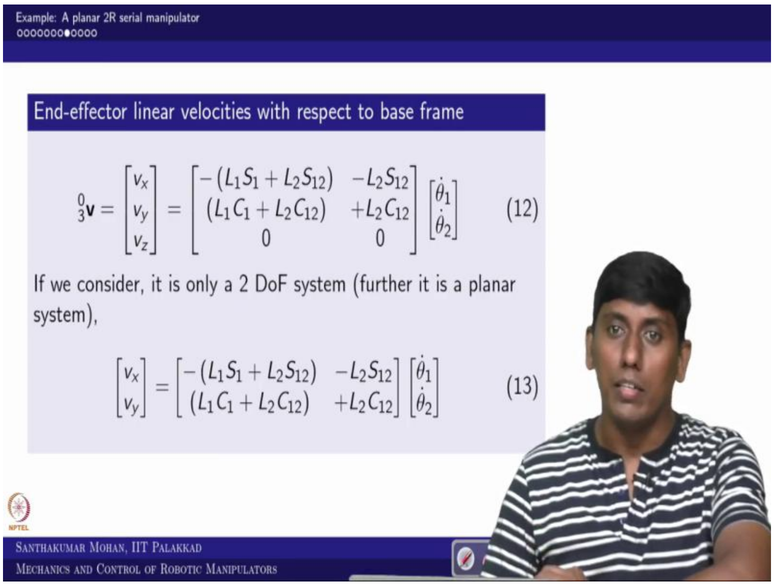

That is also like we have seen in the last class. So, now the same thing, can we do it in MATLAB in the same format yes, we can do it. So, for that if you are used the live script even it would give in a symbolic manner, but we are not doing it live script, we would be using a simple math script. So, we can see MATLAB script code.

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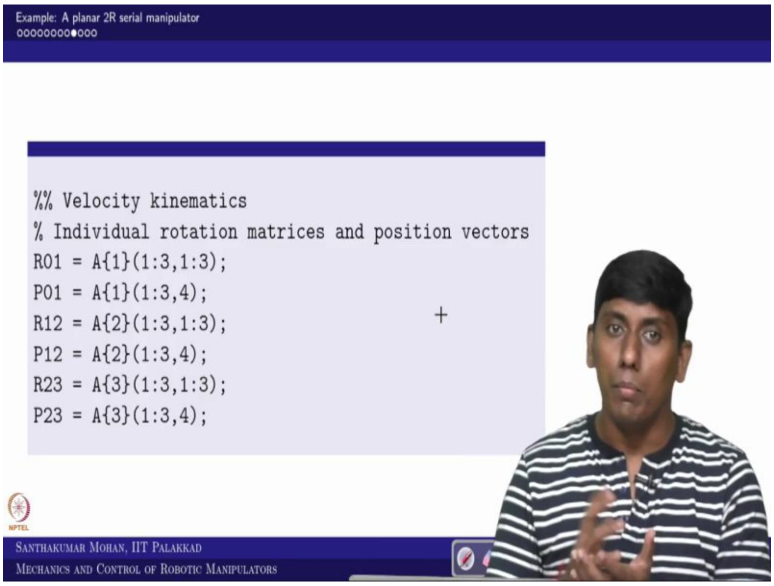

So, for that I am showing the code here. So, these are the velocity, you can say kinematics which we are trying to do it. So, for that we are taking the rotational matrices and position vectors, which we have obtained from the previous you can say simulation code, we can obtain where A would be the cell that would be having 3 cells.

So, each cell would be having a rotation and position, rotation matrix and position vectors. So, from there you can take, for example if you take a 1 which is the first cell, the first 3 cross 3 would be corresponding to the rotational matrix and the next you can say 3 of the fourth column would be equivalent into position vector, this is we all know.

So, the same way we can do it for the second cell and the third cell. So, now what we have done, so previous code we have taken and from that, we can find the rotation matrices and position vectors, once we obtain this.

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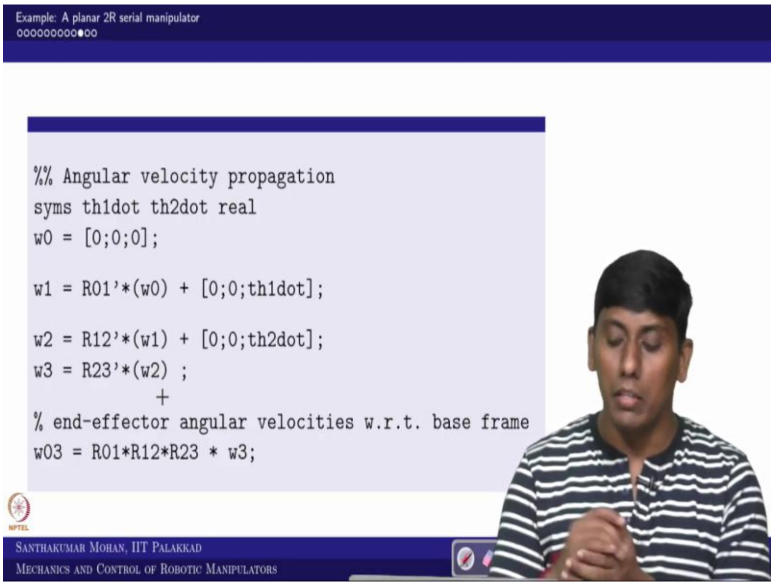

So, what we can do we can do the angular velocity propagation, where we can see there are 2 additional variable would becoming virtually these are theta 1 dot and theta 2 dot, so here we cannot write theta 1 theta 2 dot I have returned th1 dot th2 dot, so both are I represented as real and further what we have taken, we are taken that the base angular velocity would be starting from 0 because it is fixed. So, in the sense of omega 0 which I have written as w 0 equal to 0 0 0 in the sense, you can say zeros of 3 comma 1.

So, now, once you obtain this what we can do, we can substitute the velocity propagation model where omega i plus 1 to i plus 1 which we can write as R i plus 1 to i, omega i to i plus, so the variable is addition in this case, so we have already know the rotation matrix that transpose would be coming here because it is inverse and omega 0 is known and this is the active joint. So, theta 1 dot is added which is third quadrant, not quadrant third element, in the sense z axis. So, this will give omega 1 which I have written as w 1.

So, similarly we can calculate w 2 and we 3 once you obtain w 1, you can calculate w 3 and you can calculate w you can say 2 and 3 through this sequence. Once you obtain what one can do. So, this is equivalent to omega 3 with respect to third frame. So, in that sense, you can calculate what you can say. So, the omega 3 with respect to 0. So, these are the things we are trying to see it in MATLAB. So, let us go one step further.

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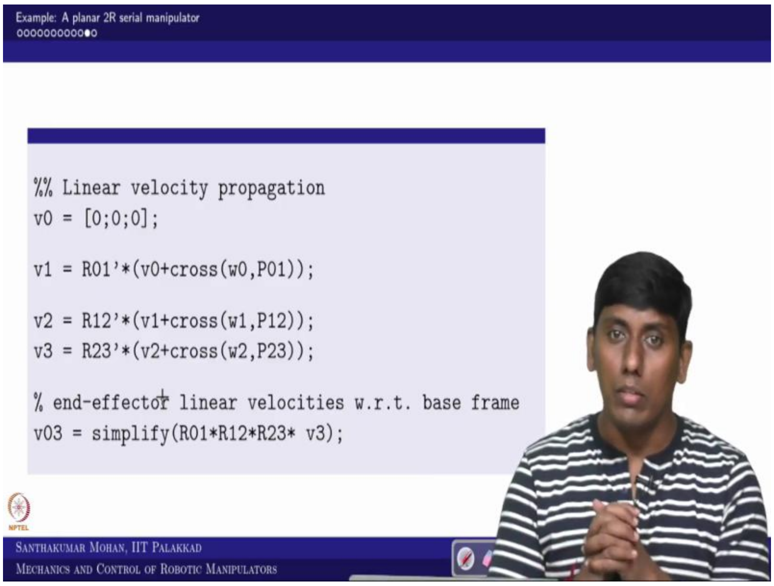

So, what we can do we can try to understand the linear velocity propagation. So, for that again the base we are starting the base it is fixed, so the linear velocity would be 0 0 0, if it is put it on the mobile base then this would come with the mobile base velocities. So, once this is all done, so we can go the velocity propagation model where the slip velocity and the tangential velocity would be coming.

So, once you calculate this, so v1 then v2 and v3 we can calculate, once you calculate v3 you can get the v03 in a sense, so velocity of third frame with respect to zeroth frame we can calculate. So, here the simplify command is just to simplify the overall equations. So, now we will see this further.

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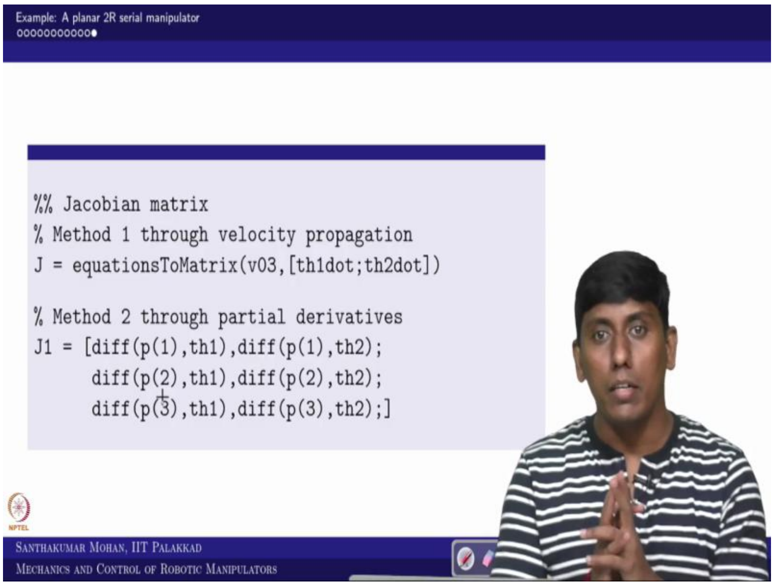

So, once you obtain this what one can do, we wanted Jacobian matrix which would be you can say coefficient of your you can say theta 1 dot and theta 2 dot, so this coefficient we can use a simple MATLAB command called equations to matrix or once you know the position vector from the forward kinematic model, you can do the partial differentiation with respect to Q vector. So, that is what we have done here. So, now we have all seen, so how the MATLAB code look like in a slide format, we will go to the original MATLAB code.

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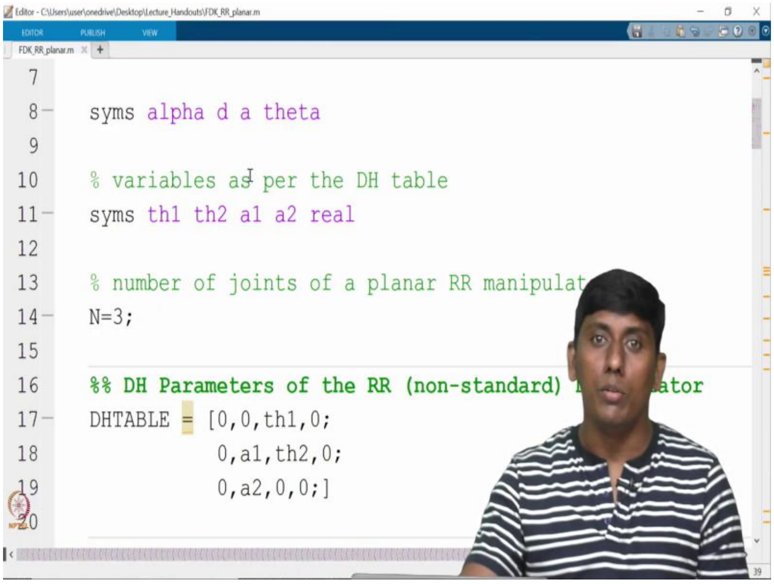

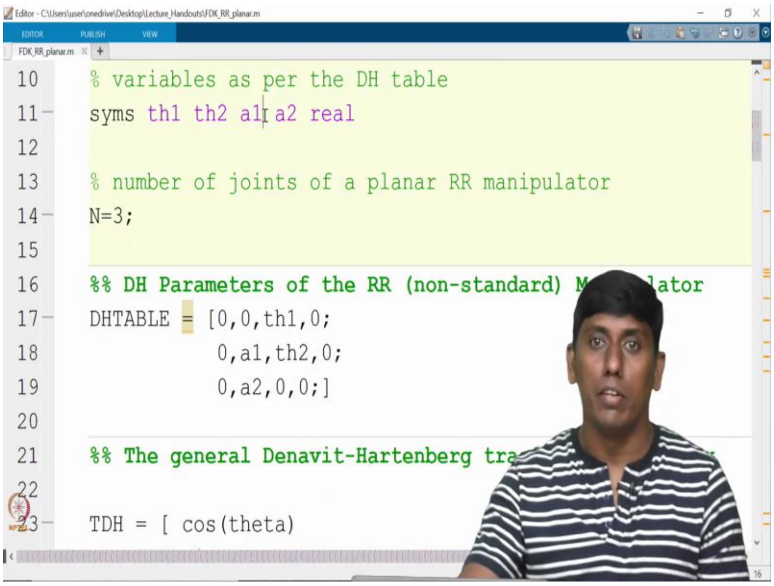

So, this is the direct kinematic you can say code which we have done in the previous simulation class. So, this is the; you can say the generalized variable and a variable based on the DH table we have actually given and here the number of joints are including you can say end effector it is 3. But excluding the zeroth frame.

Then the DH parameter as per the table which you are derived that we can substitute and the arm matrix we can actually get it here we are going to use the non standard one So, these all we have seen. So, based on that what one can see, you can actually create A would consist of 3 cells. So, each cell would be having a transformation matrix. So, these all we have seen in the previous simulation class. Right now, what we are taking.

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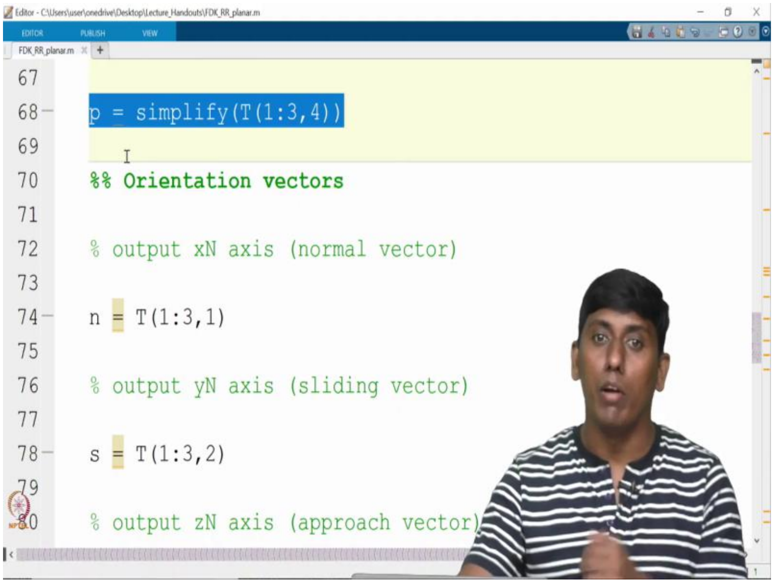

So, we have taken the P for the Jacobian, but right now we are trying to see the; you can say velocity propagation model.

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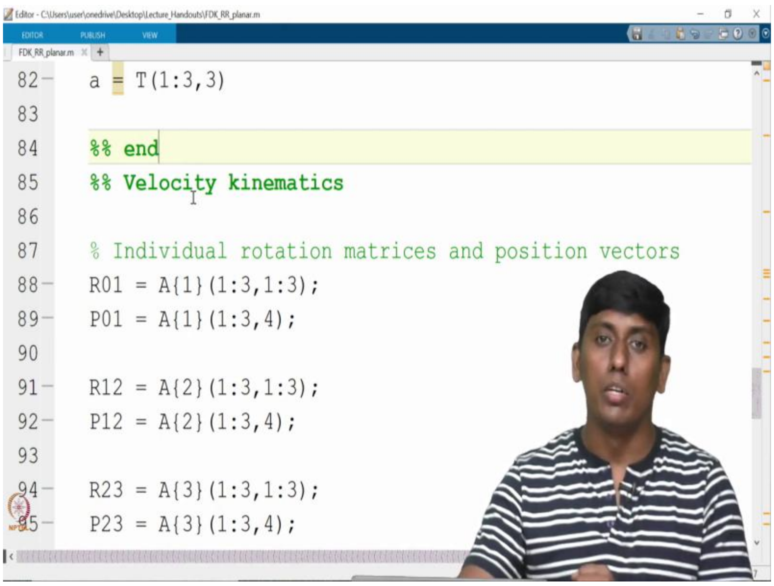

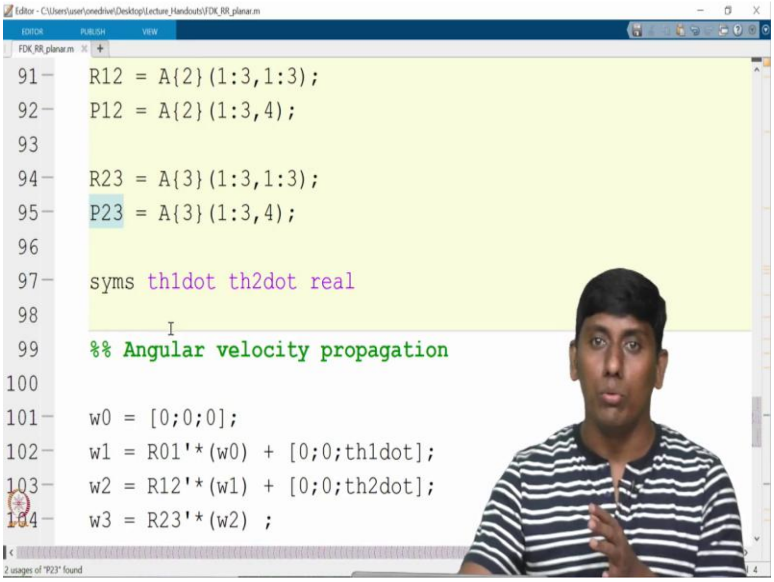

So, for that we are actually coming to the velocity kinematics. So, till last simulation class we have ended at this end. So, we are adding the code whatever I have shown in the slide here from starting from here. So, this is the velocity kinematics. So, for starting the velocity kinematics you need to know the individual rotation matrices and position vectors.

So, this you can get it from the you can say cell which you have created in the previous direct kinematic model. So, these all we have obtained. So, in this case rotation matrix of 1 with respect to 0 2 rotation matrix of 3 with respect to 2. Similarly, the position vector 0 1 with respect to 0 2 position vector of 3 with respect to 2. So, these are all we obtained.

So, then we are going to the velocity propagation for that we need to create a variable. So, here there are two active variables which is theta 1 dot and theta 2 dot which we have written as theta like th1 dot th2 dot which we consider as real.

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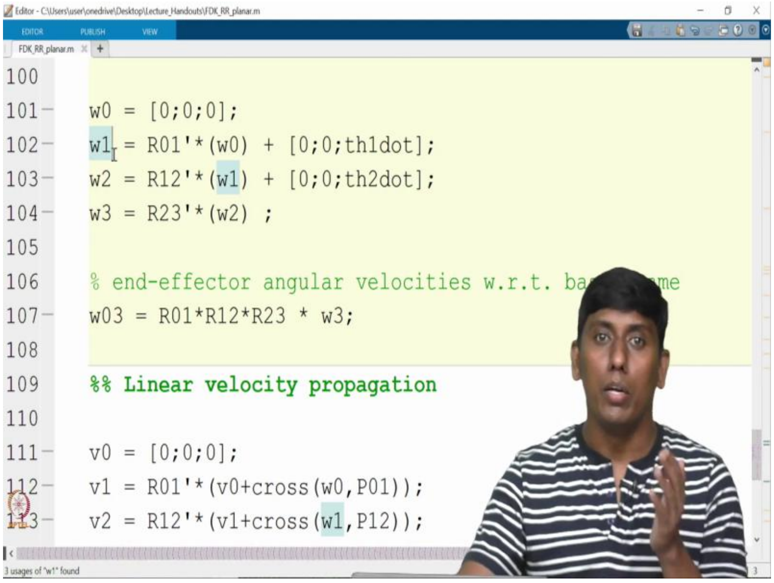

So, now this is the; you can say code which is taken from the velocity propagation. So, once you have the angular velocity is zeroth frame is known, then you can calculate the further proceeding frames 1, 2, 3 and all. So, this is the code, and we can find the end effector angular velocity.

So, then we can go to the linear velocity propagation because the linear velocity propagation required both or you can say previous frame linear velocity and angular velocity and position vector. Position vector by the way we got it from the direct kinematic model, but the angular velocity needs to be calculated that is why we have calculated already. So, now we can do the linear velocity propagation.

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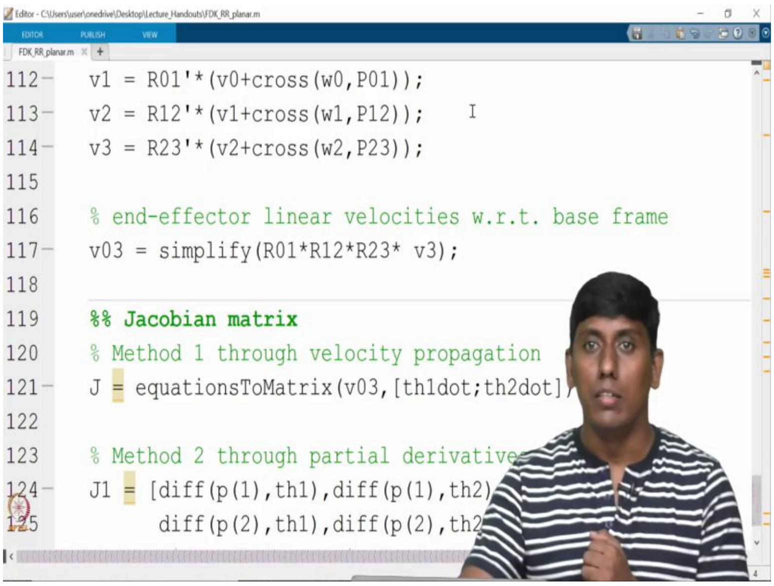

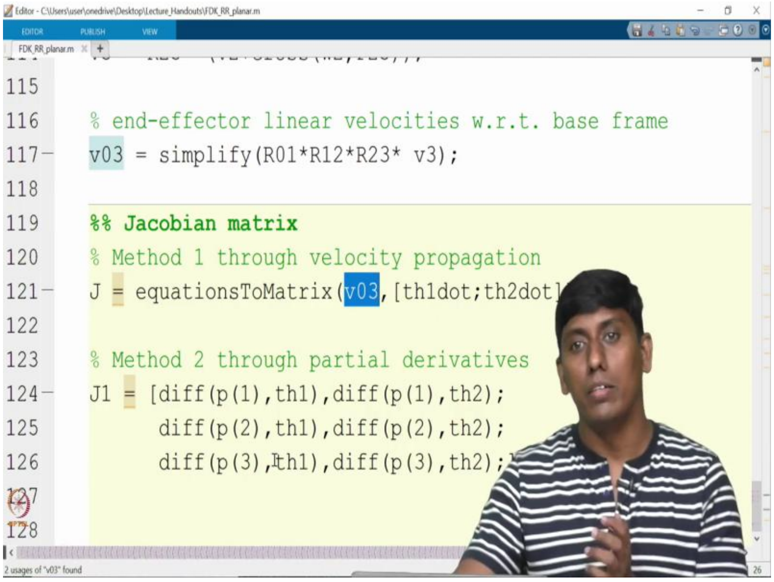

So, these are the propagated model. Since in this particular example, there is no linear joint, so everything is rotary, so there is no addition of D 1 dot or you can say D 1 i plus 1 that is we have not added. So, finally you can calculate the 3. So, with respect to base also can calculate. So, now this is what the end effector linear velocity with respect to base. In the sense, the end effector velocity, which is here as a third frame that velocity with zeroth frame you can calculate, which is as equal to Px dot Py dot Pz dot.

So, since it is in a planar the Pz dot will be 0. So, we can take from there I already said, so the command called equations to matrix we can do it. So, where v03 is the final end effector velocity, so I want to get it that partial derivative. So, I can take it a coefficient, this is one way or the other way, you can do it method through partial derivative.

So, we will go one by one. So, as I already said, I have minimized this editor window. So, you click the editor window, and you can run this code. So, this code is actually like, you can say error free.

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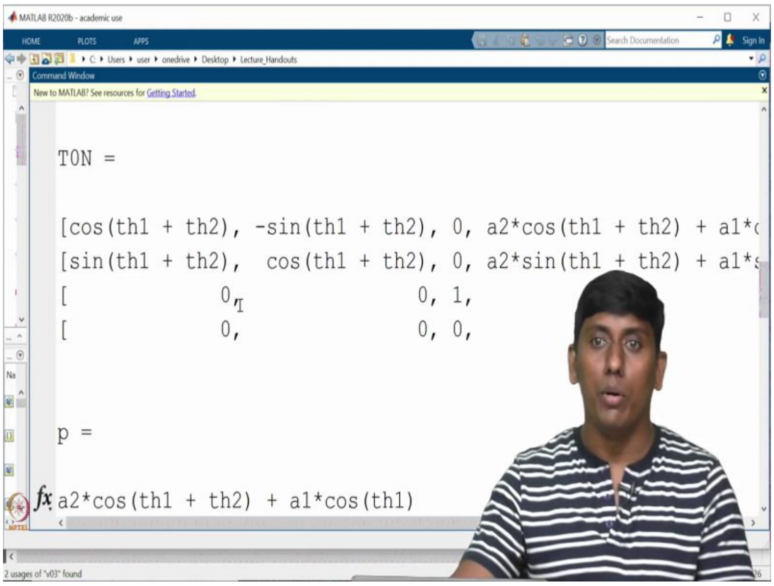

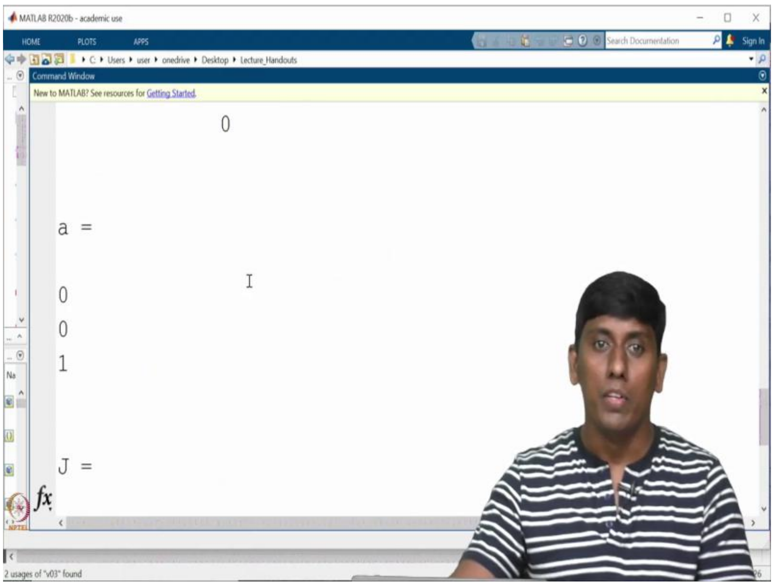

So, now if you ran this code, you can see that the result would be obtained here. So, we can start from this. So, these are all we have seen in your kinematic model. So, up to what you call approach, we will start from what you call omega 0, omega 0, we have, I will put it.

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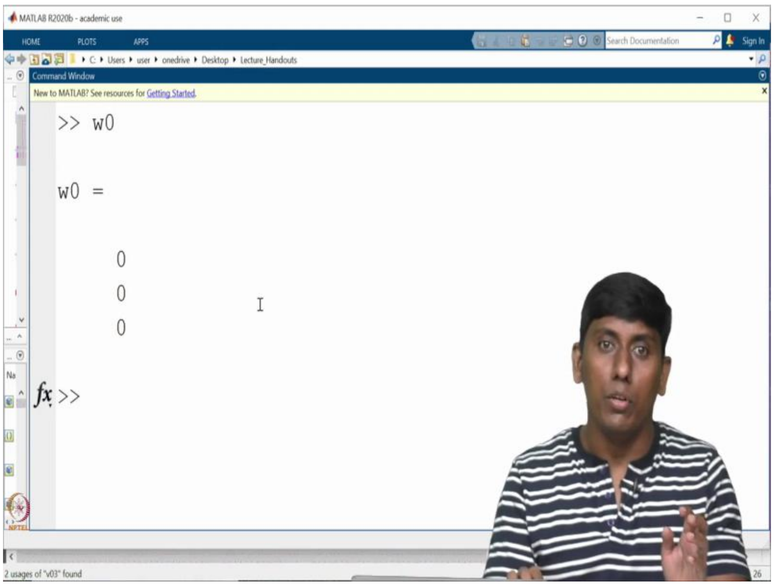

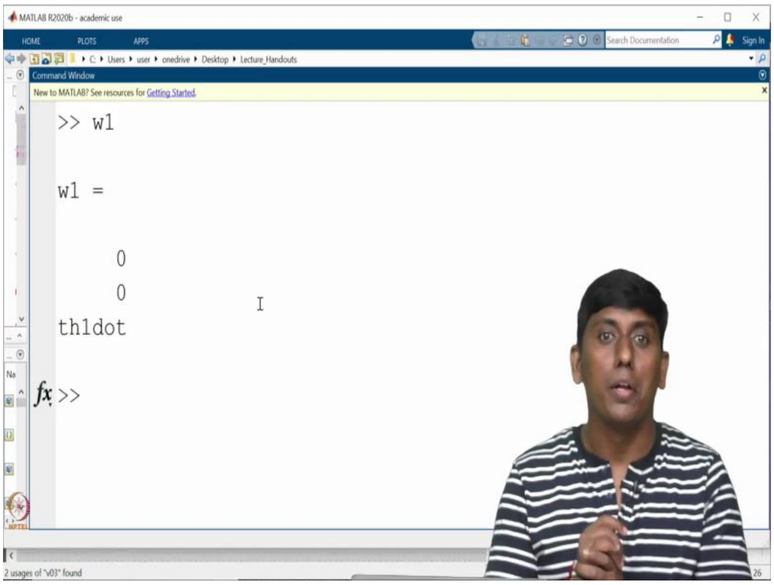

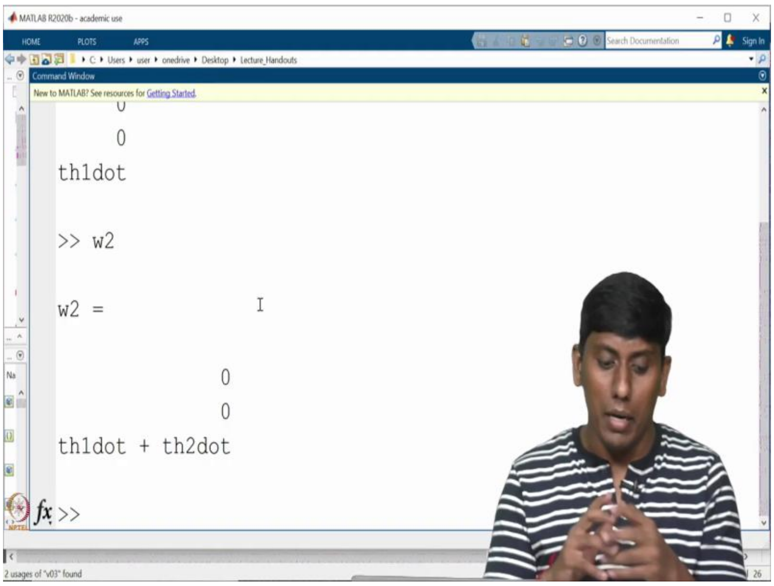

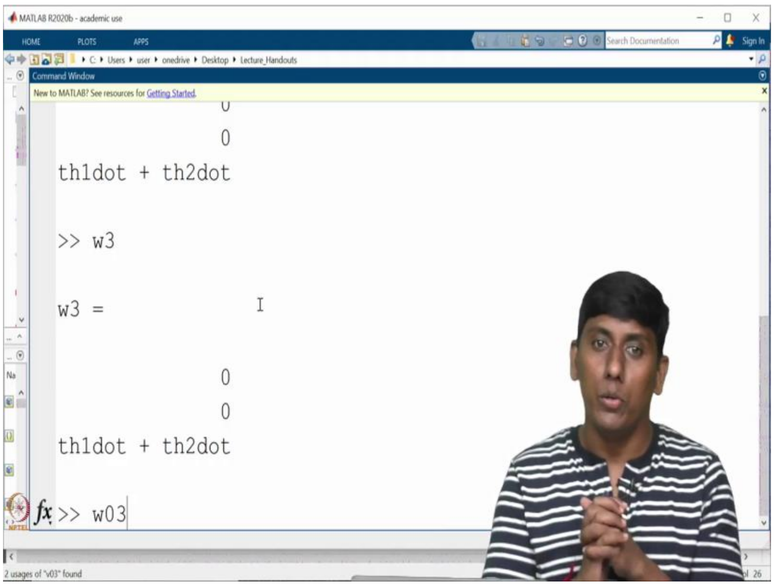

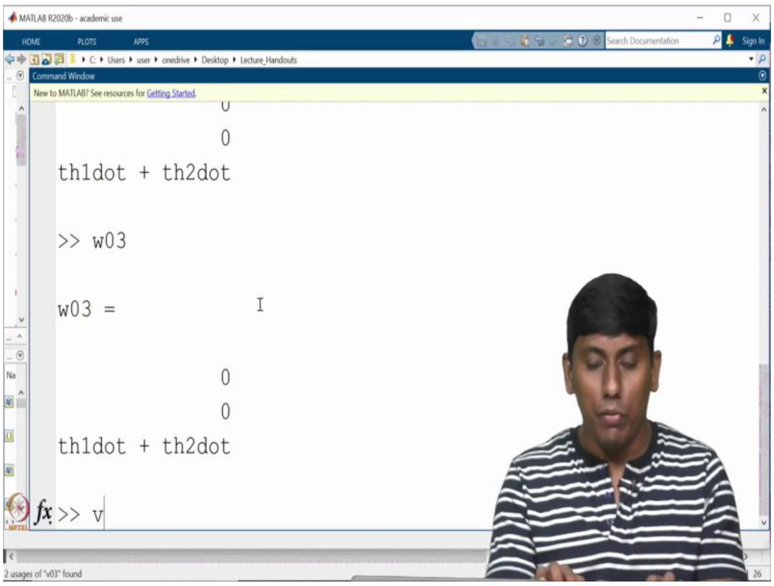

So, omega 0 we have considered as 0 0. So, we will see what is omega 1 omega 1 which we got it from the analytical model list, so 0 0 theta 1 dot whether we are getting it or not, yes, we are getting it. So, similarly, omega 2 would be theta 1 dot plus theta 2 in z axis. So, that is also we obtained.

The same as you can see omega 3, because it is the same link that is also, we obtain. So, now we can see, what would be the end effector. So, end effector also straightforward, because it is actually like, simple but you have a rotation matrix, if the theta 1 and theta 2 are nonzero, then that also will play, but in this case, I do not think that would be having a play, because your rotation matrix would be, so cos theta 1 plus theta 2. So, like that it comes.

So, this all you can say thetas would be in the x and y, but your omega 3 is having x and y is 0 0. So, that is what you can see. So, in the sense, so the third frame, you can say z axis and zeroth frame z axis all are parallel. So, in the sense whatever you have the third frame velocity that would be directly transformed to you can say with respect to zeroth frame. So, this is correct, you got it. So, this is we are verified in the analytical, analytical also giving the same.

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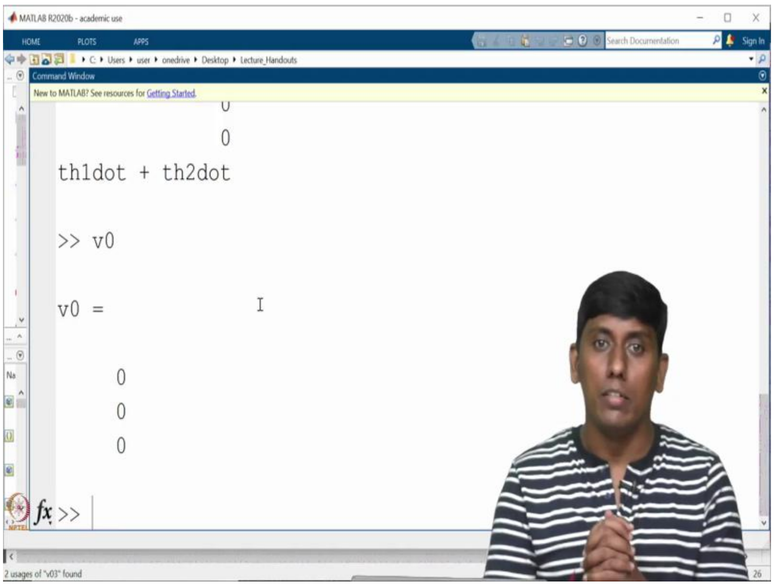

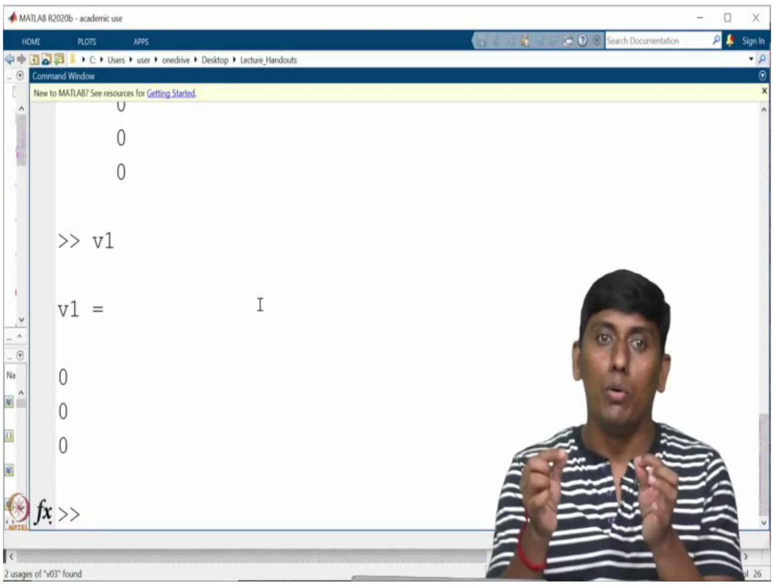

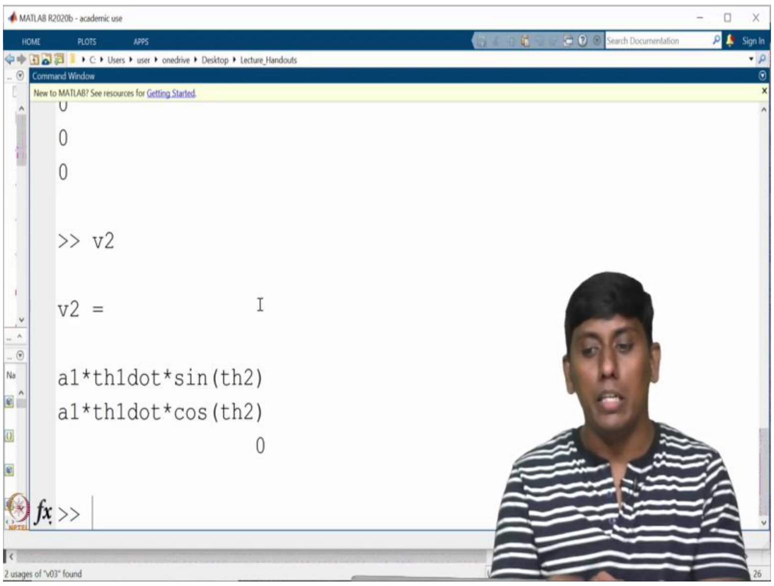

So, we start from v 1, so v 0 we assumed as 0. So, v 1 would be what we expect because 0 and 1 on the same point, so there would be 0 linear velocity that is what we have seeing in the analytical also. So, here also the same, but when you come to the second you can see, so there would be L1 distance, and the tangential velocity would be coming. So, that would come here.

So, if you put theta 2 is 0, so what you can see, if you put theta to 0, so it is velocity would be only in y axis that is very clear, a1 theta 1 dot would be the magnitude that would be direct parallel to Y axis. So, that is visible here also and the x axis 0 velocity that is also clear. So, now, you put theta to is 90 degrees. So, you can see in that case.

So, a1 theta 1 dot would be having perpendicular which is approach side. So, that is also. So, a1 theta 1 dot would be there. So, in that sense this direction, but if you take it from zeroth frame that would be a negative direction, that you can a cross check it.

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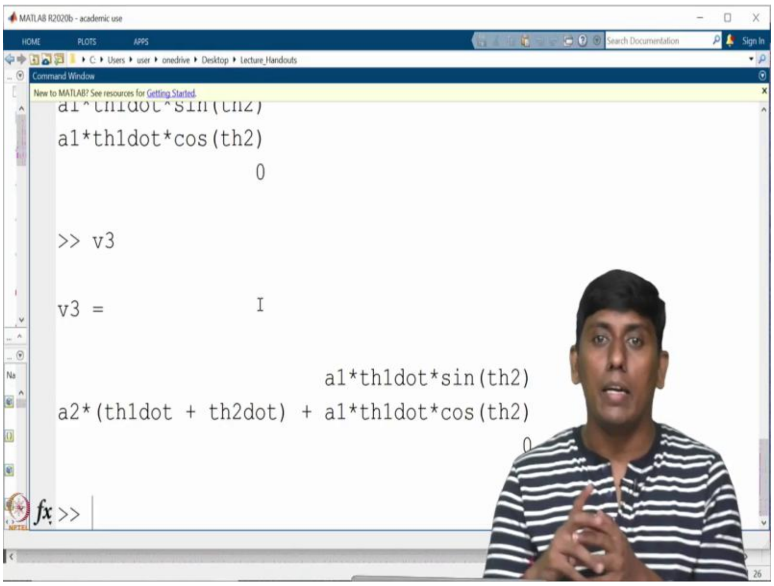

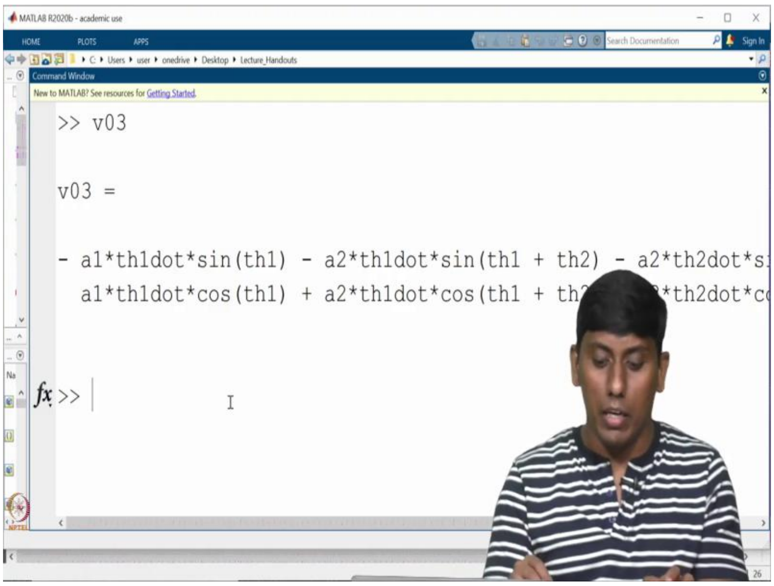

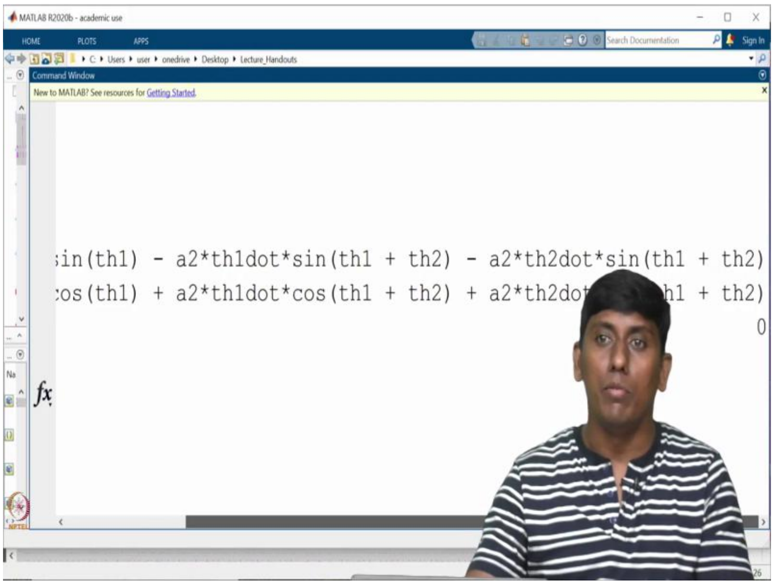

So, let us go to the v3. So, v3 would be added. So, I will show it clear. So, these are the v3 components. So, you can see now, the v3 the x axis 1 velocity added but y axis you can see something is addition. So, this is all with respect to something but what we wanted. So, v03. So, so, v03 is what you wanted, so this is having a lengthy equation. So, but this lengthy equation you can reduce it to a simple one.

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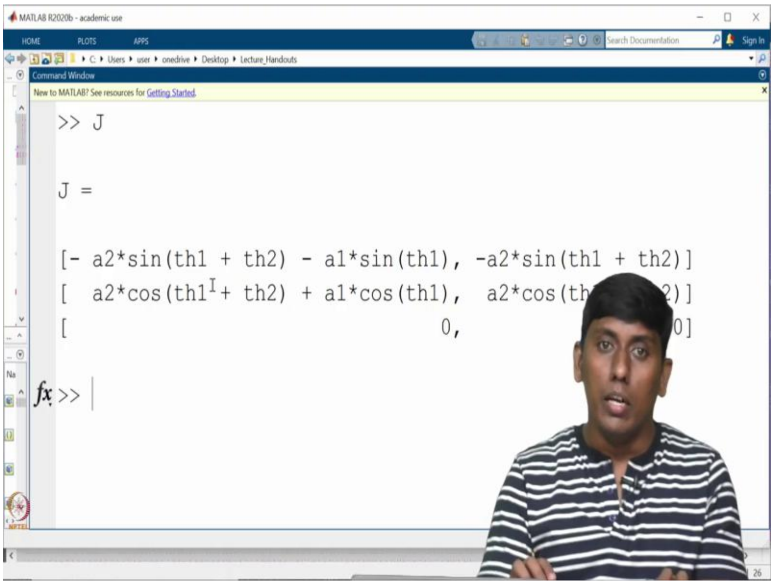

So, for that what we are trying to do the Jacobian. So, you can see the Jacobian. So, Jacobian you can get it. So, you can s2ee, this is a2 sine theta 1 plus theta 2 minus a1 sine theta 1, this is what we also obtained in the earlier one and here also you can see this is a2 sine theta 1 plus theta 2. So, the minus sign is very clear. So, similar way you can see the x and y. So, in that sense, I want to show like this is the first component.

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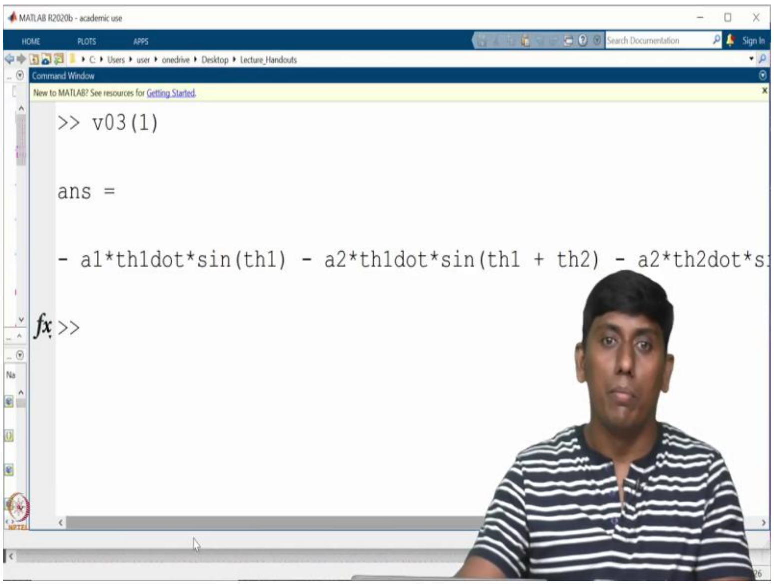

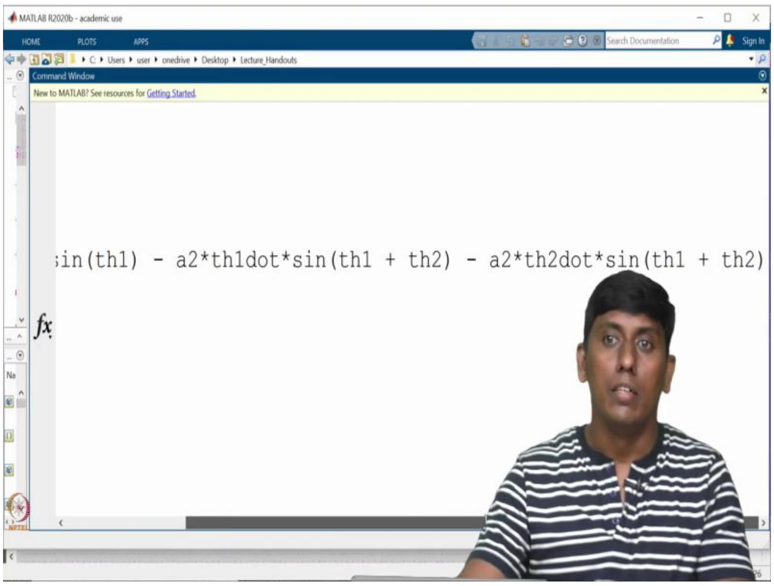

So, I will just make it this is the first component, you can see first component is having, so theta 1 dot is having you can say two places, theta 2 dot is having two places, theta 2 place is having once place. So, that is what we can see it as Jacobian.

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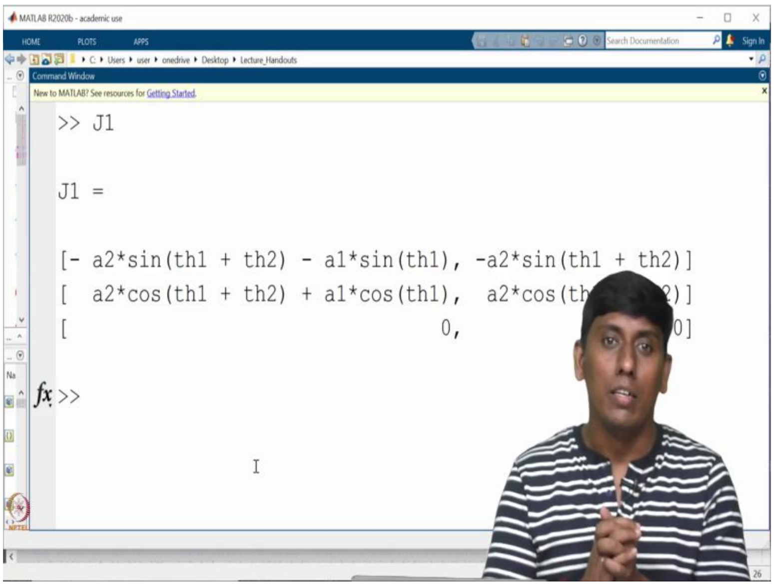

The same thing you can expect in J 1 with the partial derivative also. So, that is what we have obtained. So, you can see this is also the same case what we see. So, in the sense of what one can clearly see. So, whatever you have done in analytical the same thing, you can put it as a code in MATLAB and do it even this can be even further simplified as a simple generic code. But that is a little complex to understand. So, that is why I have written this code as a lengthy one.

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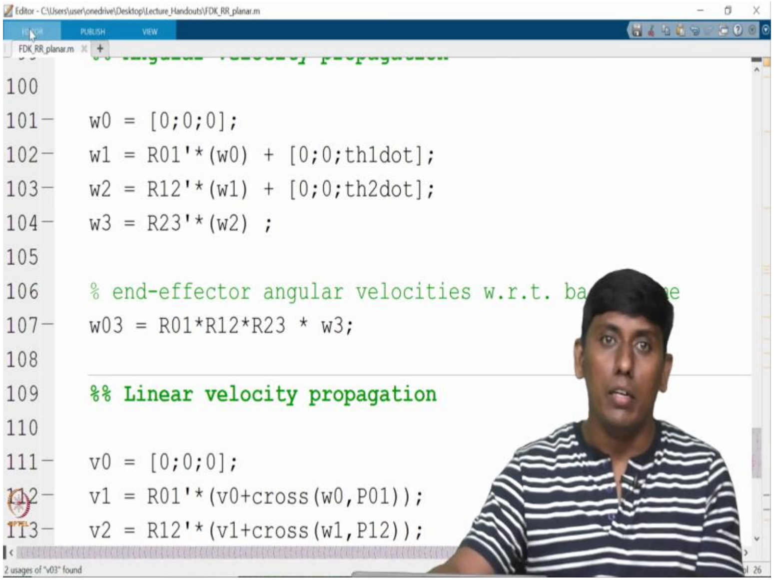

So, instead of this will omega 1 omega 2 omega 3, I can put a for loop, so where I can for loop will start from i equal to you can say 1 to n and inside I would say that whether it is a rotary joint or prismatic joint I can put a condition. So, based on that I can iterate and then I can do it, but that would give a confusing end to you. So, I have returned in a propagated way.

Some people will say that say it is a recursive one, why you have done in a sequence just to give a clarity, the same thing can be realized in you can see other one, other one in the sense we can go another example.

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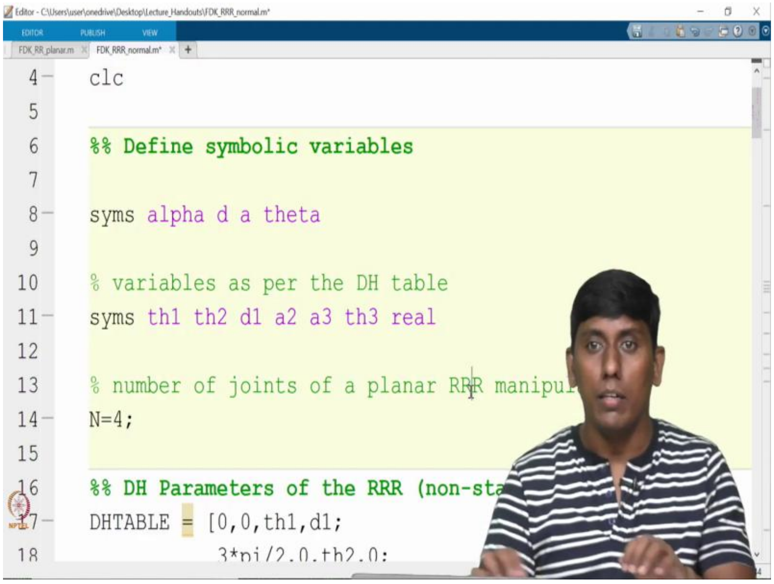

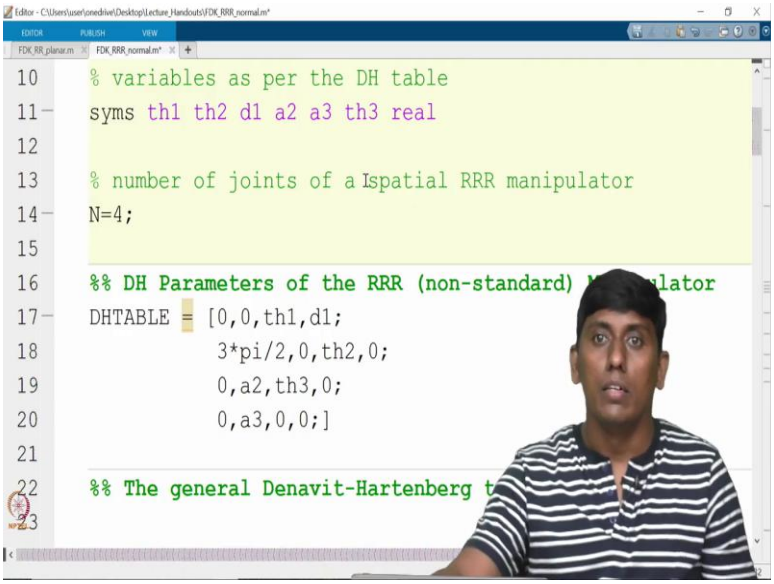

You can see that is also like seen in the forward kinematic model or direct kinematic model where the three R serial robot, we have seen, this is R R R. So, this serial robot we have seen it is spatial. So, this robot we have seen this is a DH table and these all we have seen in your previous simulation you can say lecture.

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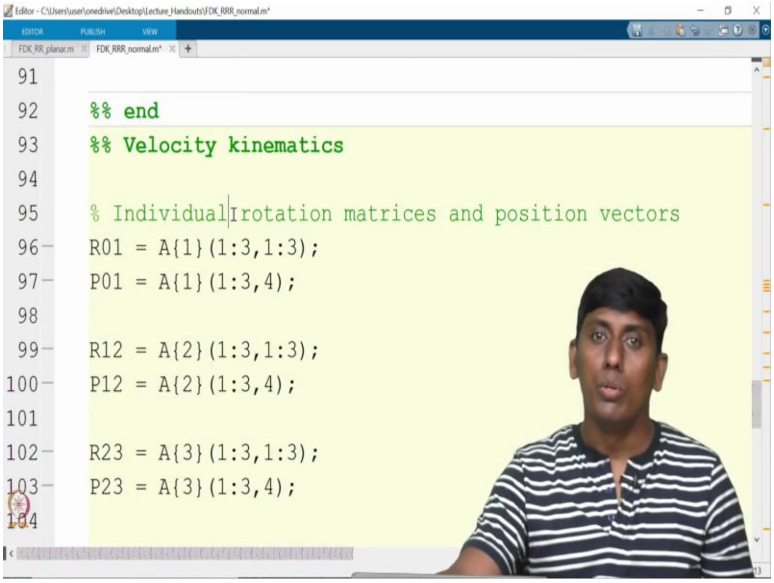

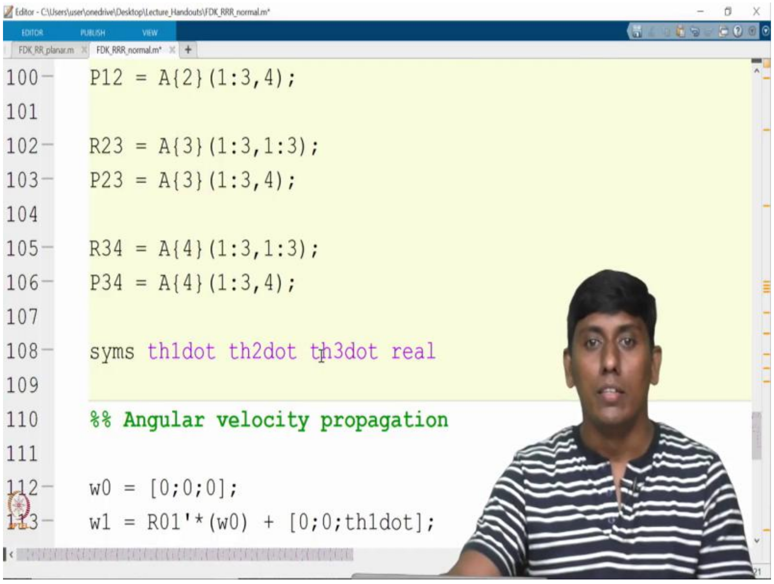

So, now, we will start only from here you can see this is the same thing what only one thing is added the rotation matrix of the fourth frame and the position vector added. So, similarly, one additional active variable which is theta 3 dot that is added and here you can see that we have actually extended up to omega 4.

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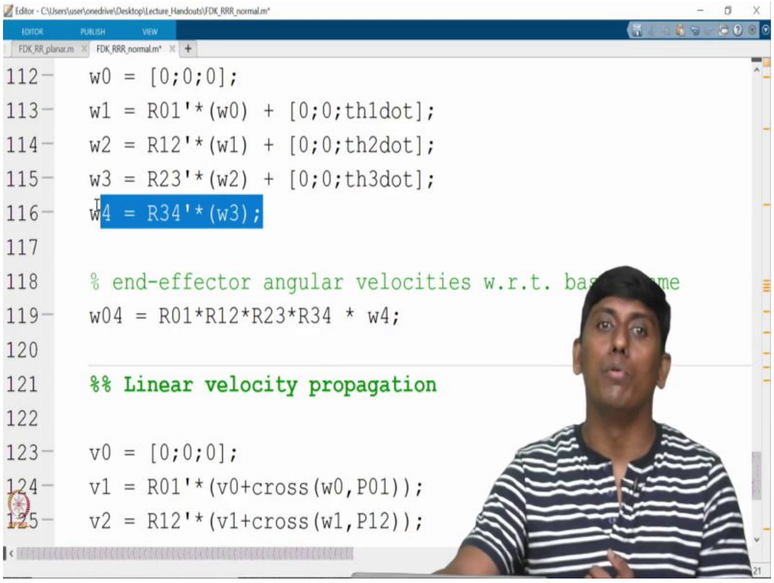

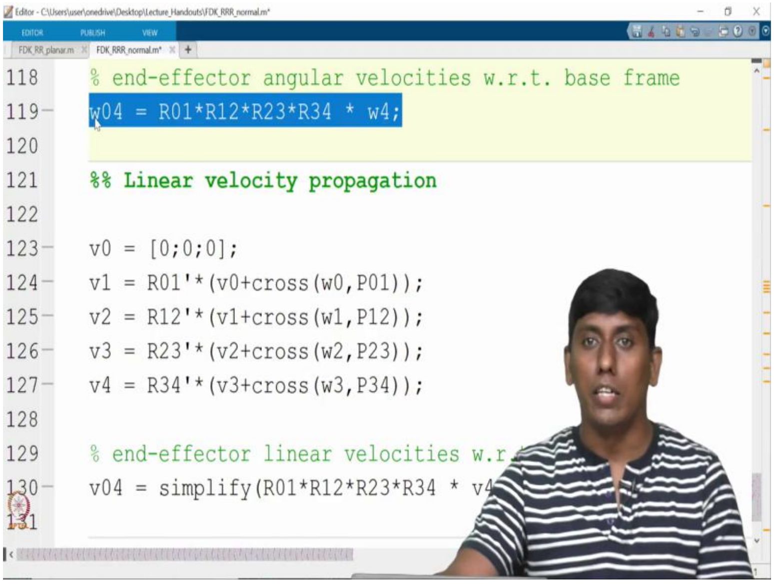

So, since we have extended. So, this end effector velocity is omega 4 with respect to 0 that is what with respect to base frame. Similarly, the linear velocity is extended up to this. So, this also we can extend. Since we know this method also giving the same result. So, I did not like what you call did the second method.

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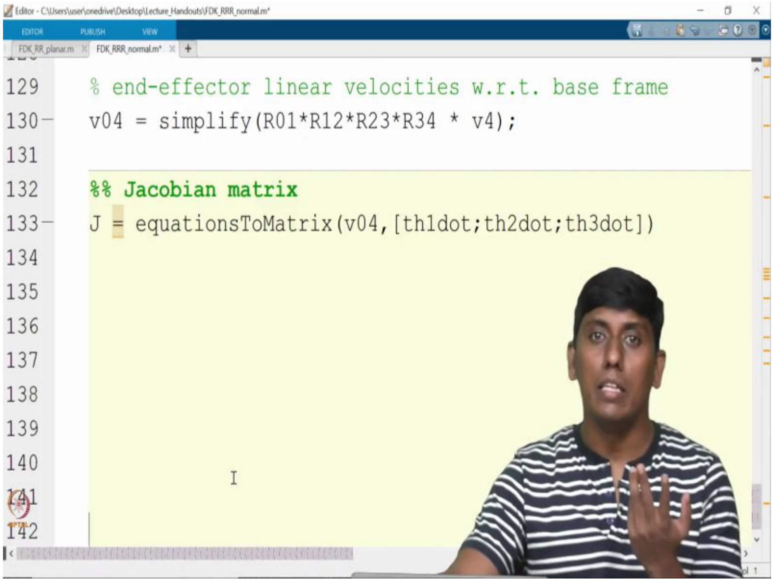

The J 1 I calculated in the earlier code that is I did not do it. So, now if I ran this obviously this will you the right result you can also like verify, I will be sure I will be sharing these codes in your lecture material. So, you can find it.

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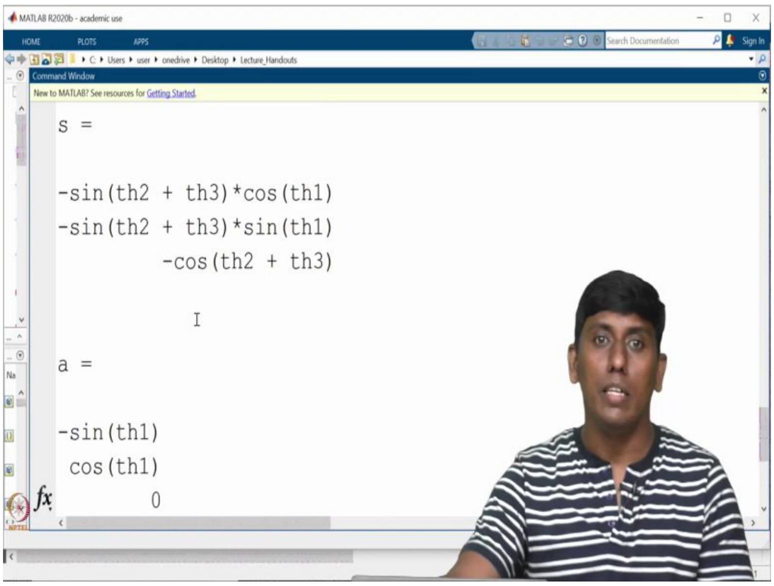

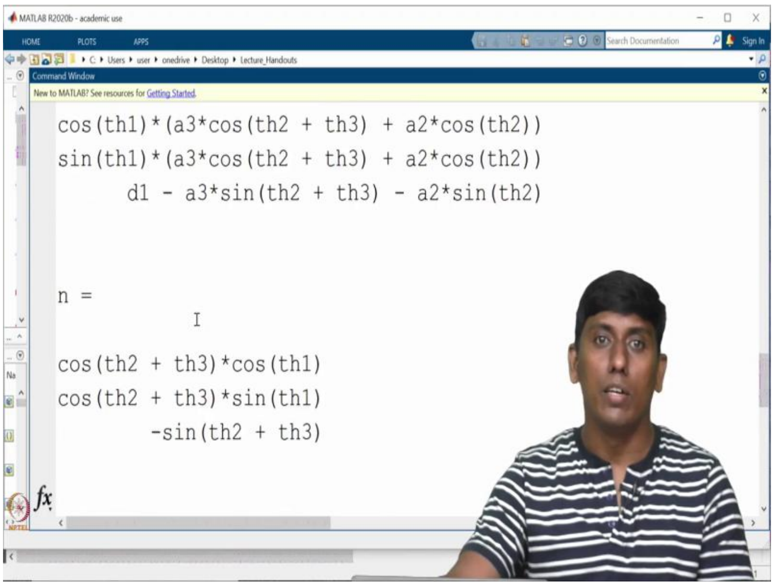

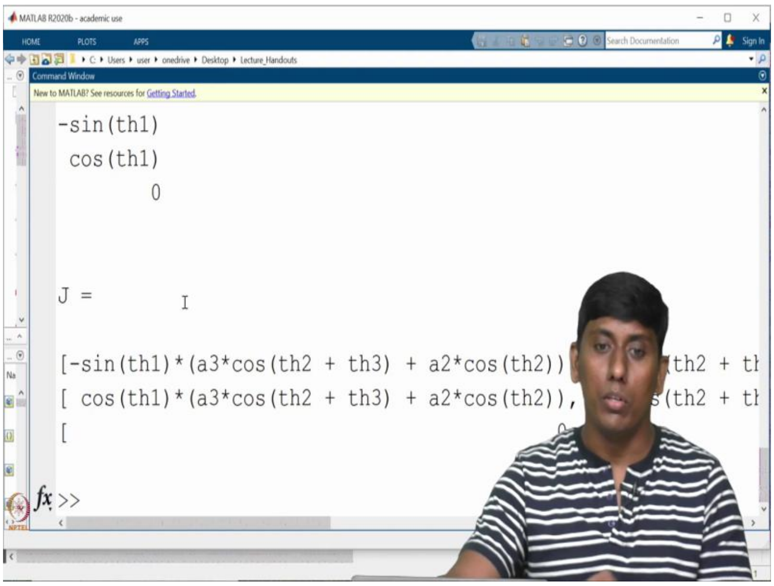

So, now this was run, and you can see these are you can say you are a normal sliding and approach vector and this is what the Jacobian.

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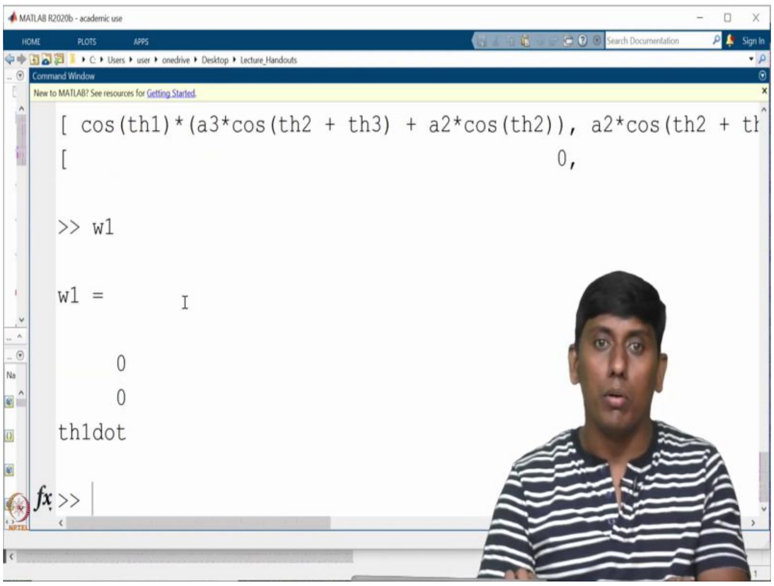

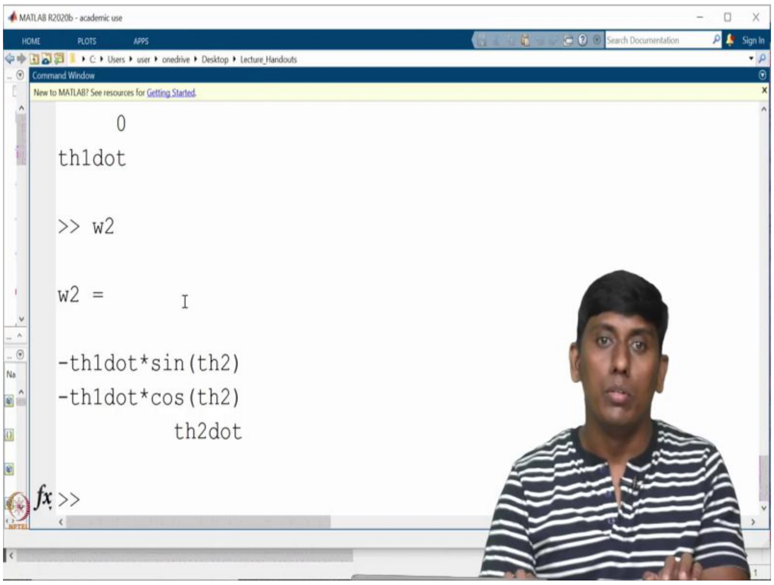

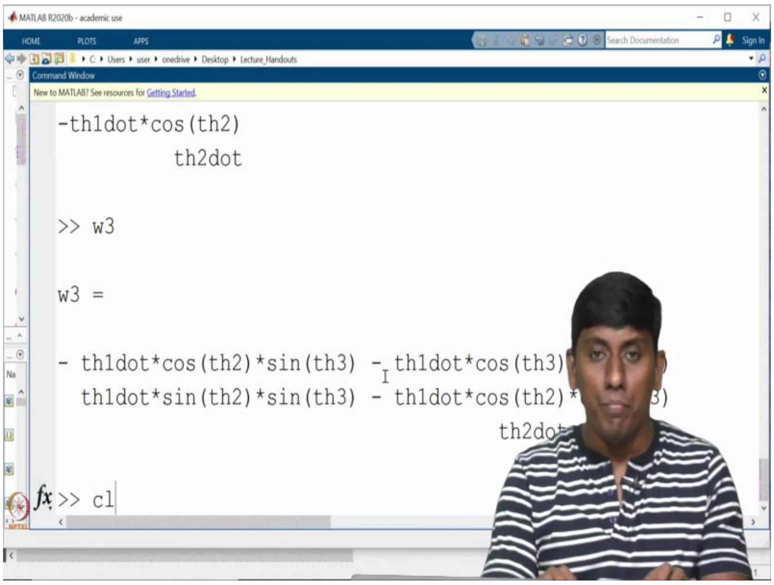

And you can see this is what omega 1 and this is the omega 2. So, here it is the first joint is vertical rotary and the second joint is planar in the y z plane, or you can say x z plane whatever plane you consider.

So, in that sense you can see that there is the angular velocity, this is theta 1 dot here, but when it comes to this axis, so it would be having a transformation that is what you can see it from this result. So, similarly omega 3 it would be parallel. So, you can see that just added.

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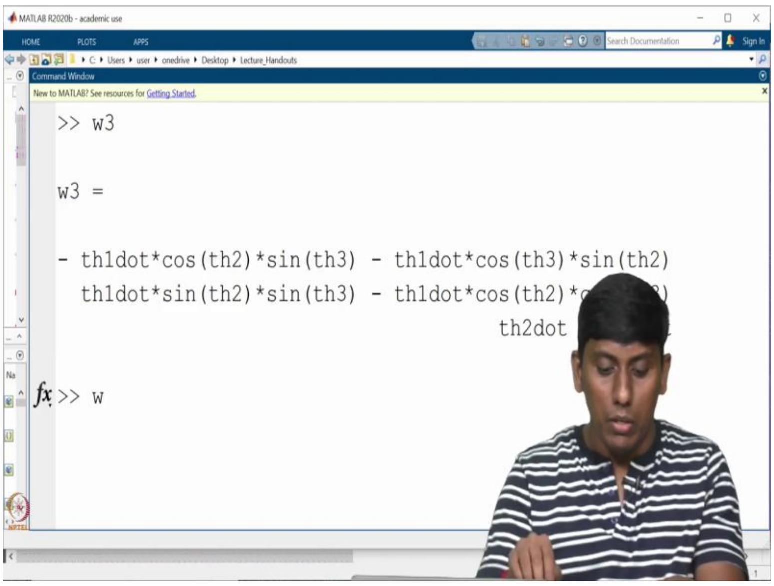

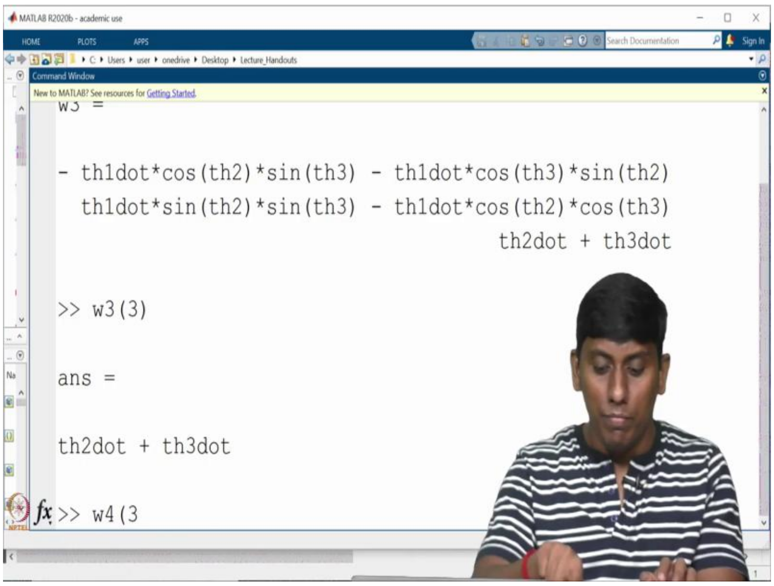

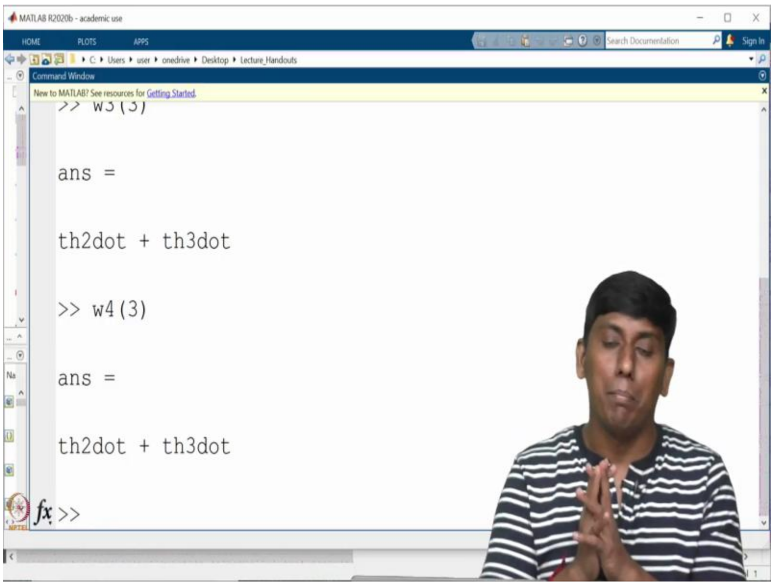

And the; what you call the coordinate would be added. So, that is it. If you look at it the third component of omega 3 you can see it is theta 2 dot plus theta 3 dot why it is, so because z axis are parallel for 2 and 3. So, the same sense if you go for omega 4 you can say 3, so that is also same because the third frame and fourth frame are the same link and the fourth frame is not having any active joint and we have assumed that both axis are parallel.

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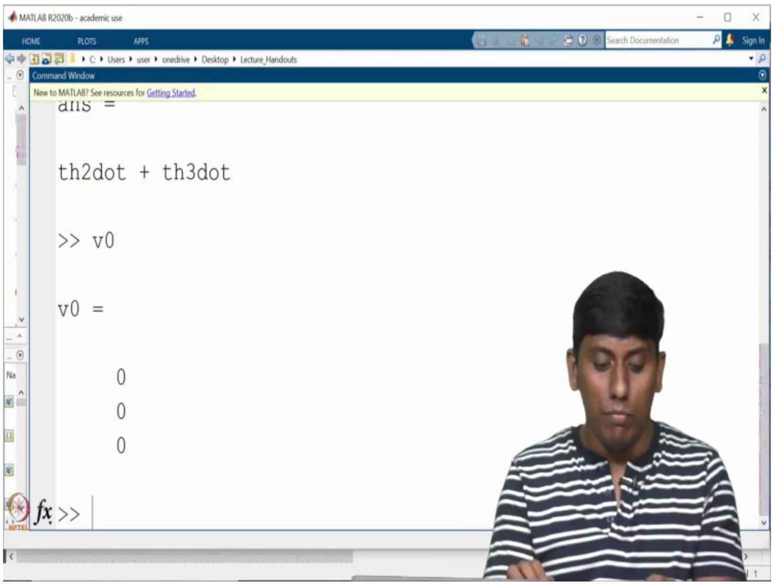
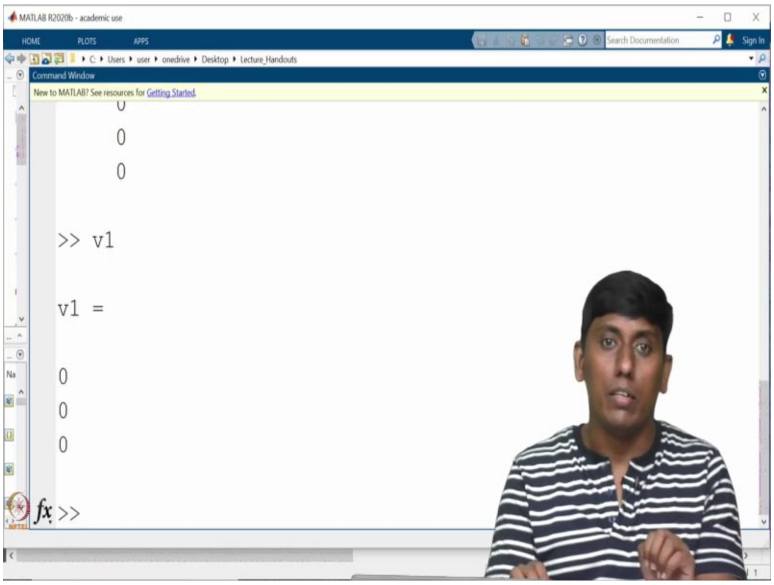
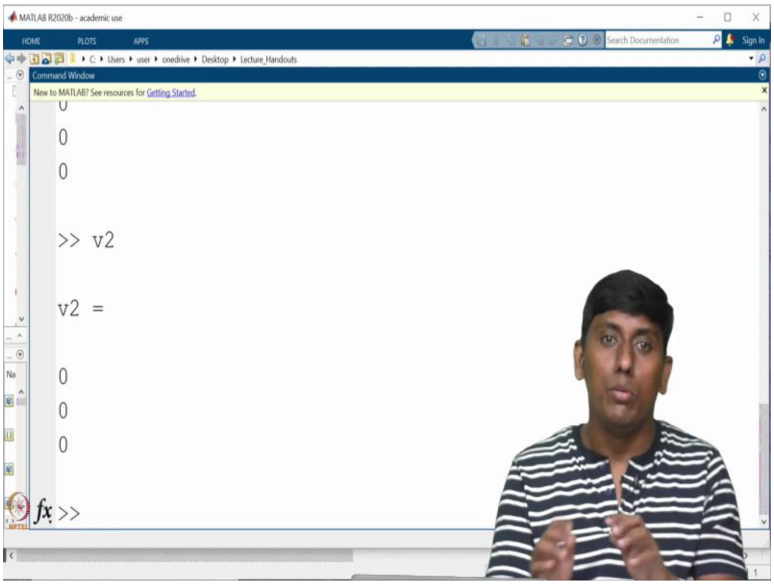
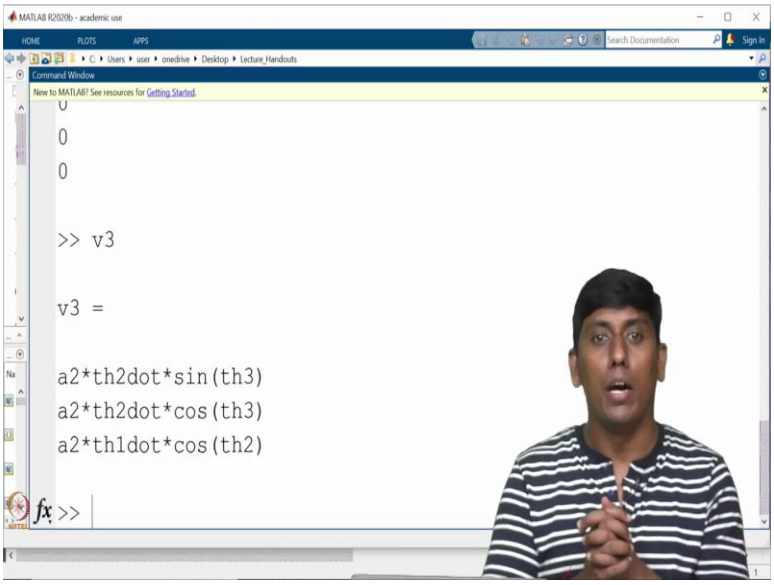



MATLAB R2020b - academic use
Command Window
New to MATLAB? See resources for Getting Started.
0
0
>> v1
v1 =
0
0
0
fx >>


MATLAB R2020b - academic use
Command Window
New to MATLAB? See resources for Getting Started.
0
0
>> v2
v2 =
0
0
0
fx >>


MATLAB R2020b - academic use
Command Window
New to MATLAB? See resources for Getting Started.
0
0
>> v3
v3 =
a2*th2dot*sin(th3)
a2*th2dot*cos(th3)
a2*th1dot*cos(th2)
fx >>

In the same sense we can start we assume 0, we because both are same point and v2 you can see 0, because in this case if you recall R R R, three R manipulator. So, the first axis comes here, second axis goes inside the you can say picture or inside the screen, in the sense 0 1 2 3 all having in the same line, especially 1 and 2 are having the same point 0 and 1 are D1 distance but the D1 distance is constant. So, there is no linear velocity happening at you can 0 1 and 2 that is why you can see up to v2 it is having 0.

When you come to the third. So, v3 you can see like that tangential velocity is coming, here only tangential component will come because we have considered all are rotary joint. So probably one additional example I may put it somewhere in the middle. So, you can see if the prismatic joint comes out it will come. Anyway, in Dynamics we will be seeing that in a prismatic. So, we can try.

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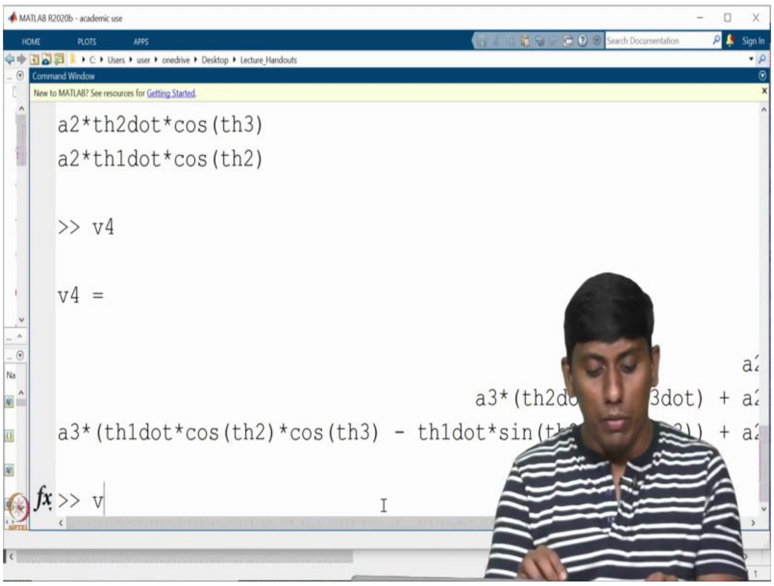

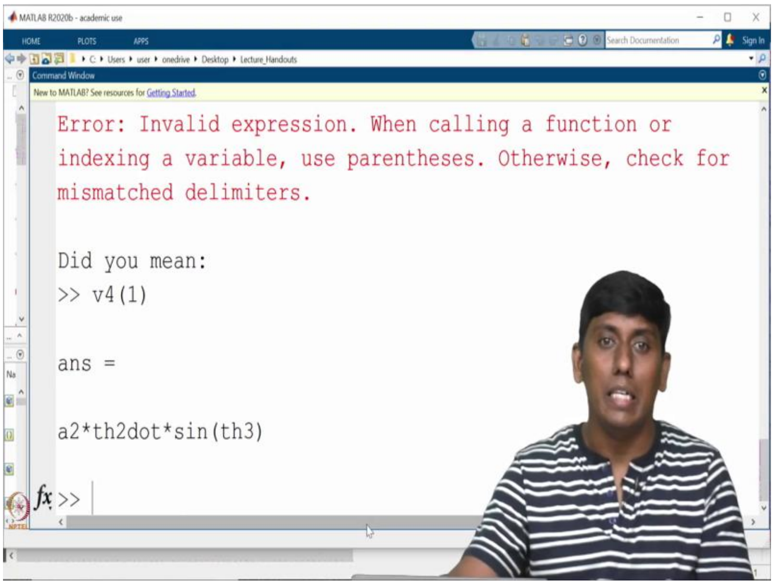

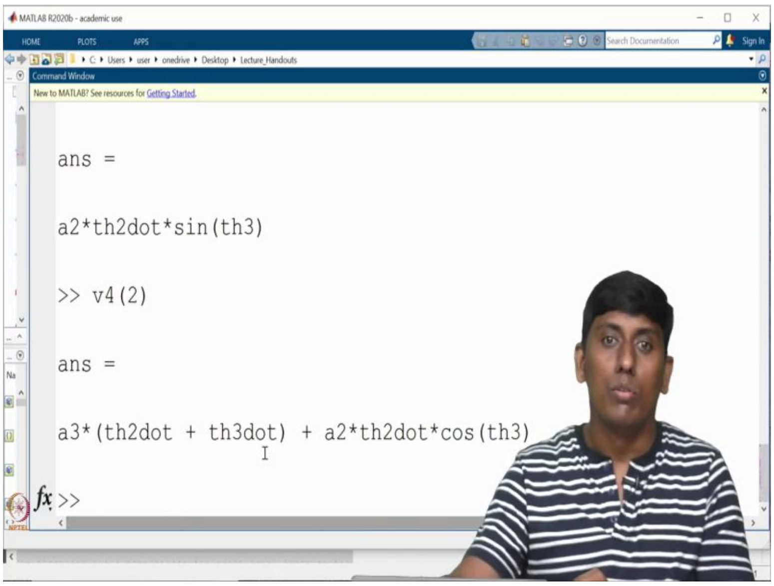

So, similarly v4 you can see, So, v4 would be lengthy because it is having a connection, So, v4 of 1, v4 of 1 you can see this is, so v4 of 2 you can see it that way. So, like that you can see it would be expanded.

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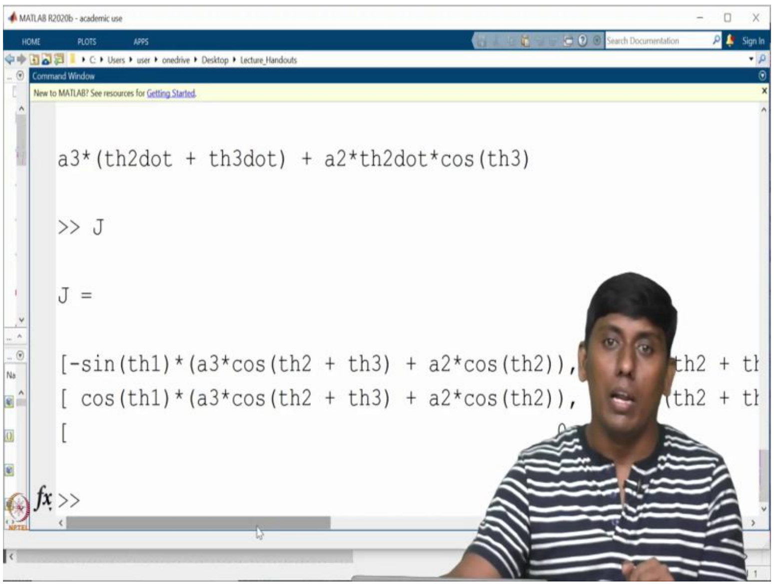

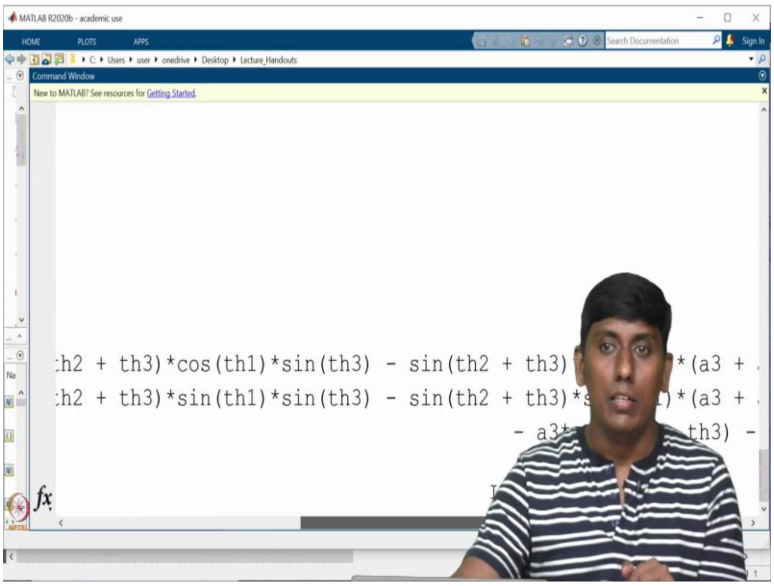

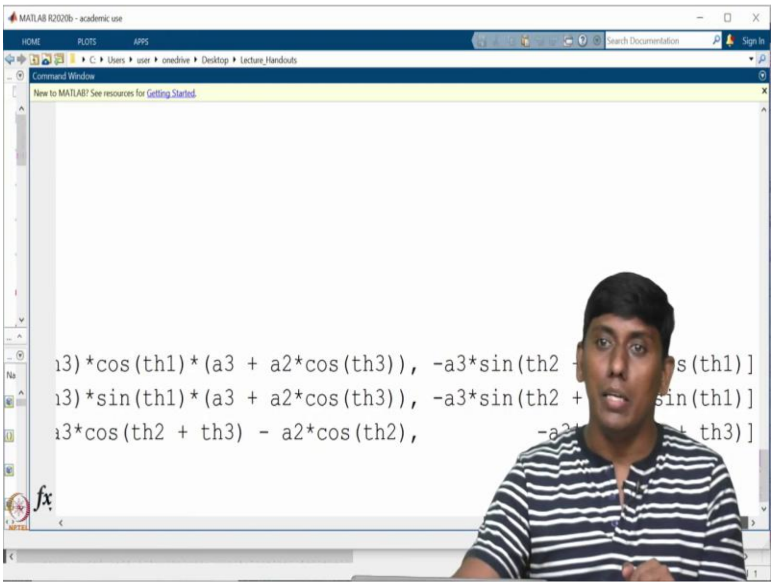

And now, you can find the J, so J would be small extension of the other one, this can be obtained with the same thing.

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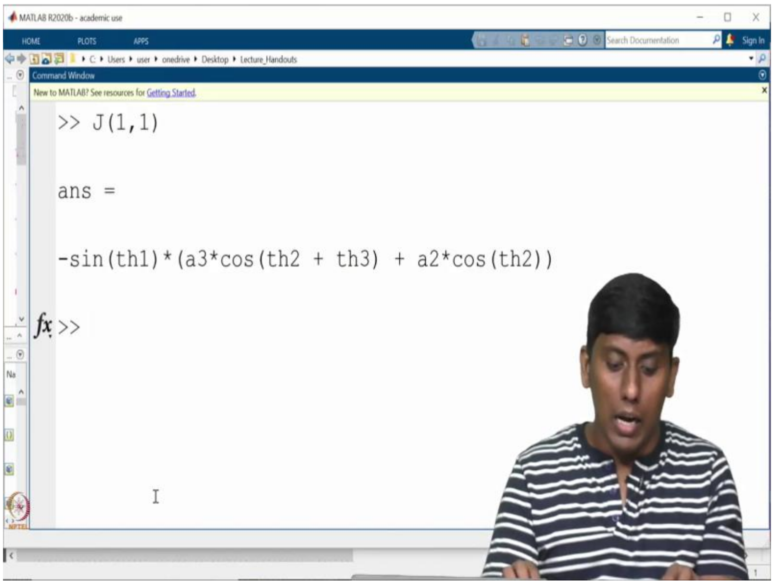

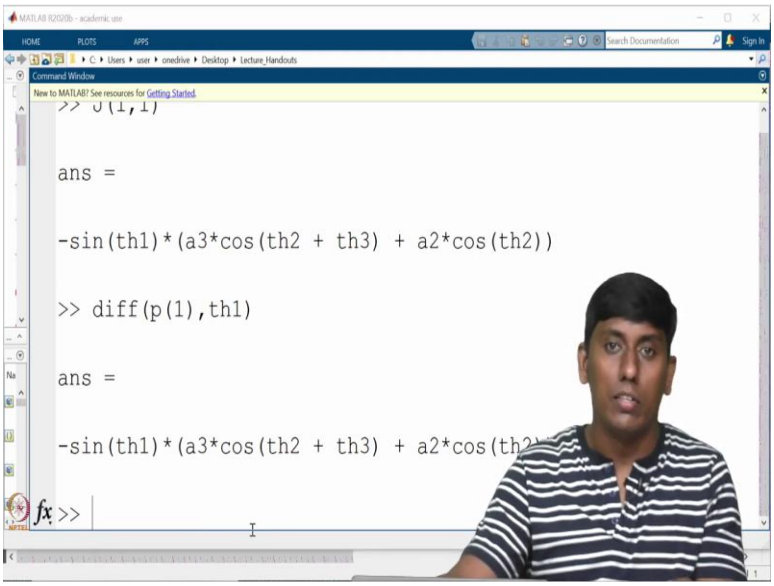

So, for example, J of 1 comma 1 I am just showing it. So, I will just make it this. So, J of 1 comma 1 and differentiation of, so P of 1, comma so theta 1 would be the same. So, what I did not simplify, so that is why it is coming, slightly different, but you can see like, these two are same. So, that is what we can see it. So, in that sense, I am ending this particular lecture.

So, where have seen like how to do the velocity propagation model of a serial manipulator with the help of MATLAB. So, this code is very generic, you can just you can say put it as long as you have a direct kinematic model which you have written in MATLAB, it is simple extension, if not, you should have a rotation matrices and position vectors in your hand and then you can it make the propagation model.

So, either way you can do it, but I already did the direct kinematic model in MATLAB I just extended, otherwise you have to write the rotation matrix then there. So, that is the only thing and please make sure, so when you are calculating omega i plus 1 with respect to i plus 1 frame, so the rotation matrix is that you can say inverse are transpose of the normal matrix in the sense.

So, when you calculate omega 1, so the rotation matrix is 0 1 transpose, or you have to write R 1 0. That is, we do not have, so we are taking a transpose of R 0 1. So, that make it clear. So, with that, we are ending this particular lecture. The next lecture would be talking about the statics, and you can say singularity of the serial manipulator. So, we can see until then, thank you. Bye.