Introduction to Soft Computing
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Lecture 12
Fuzzy logic controller (Contd.)

So, we are discussing the design of a fuzzy logic controller. In the last lecture we have learnt how the rule base which is an essential part of a fuzzy system has been developed. So, will discuss about the other, there are other modules. So, today will discuss other module namely these 3 modules. So, fuzzy inference engine, fuzzification module and defuzzification module.

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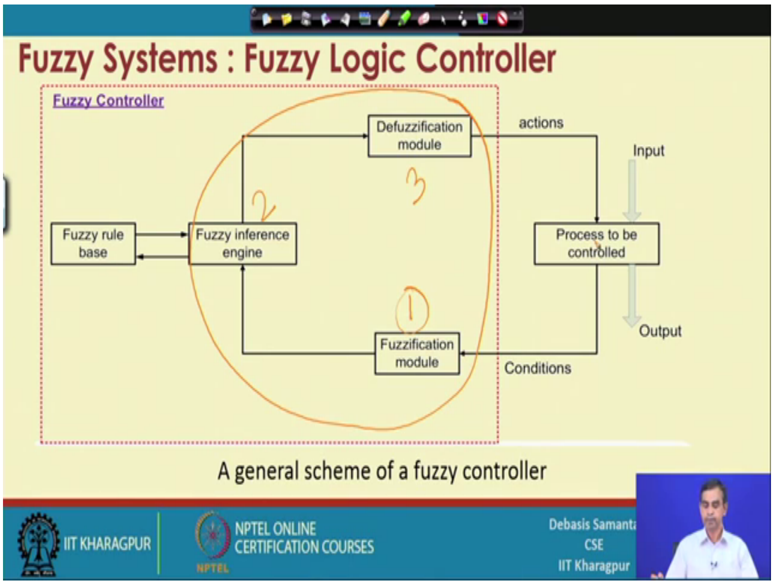

Now, so first will discuss the fuzzification module because the input it will take the data that is required to control the system and the fuzzification module will produce an output which will be used by the fuzzy inference engine. So, we should learn fuzzification module first then we will be able to discuss about the fuzzy inference engine.

Fuzzy inference engine will consult with the fuzzy rule base and then produce an output that is the fuzzy output. So, fuzzy output will be the input to the defuzzification module that is the final module in the fuzzy logic controller and we will discussed in the fuzzy logic defuzzification module defuzzification module will gives the output that output will be used as a creeps value and then helpful for the controlling some application.

So, this is the task that we are going to learn today fuzzification module followed by the fuzzy inference engine and then defuzzification module and will follow the Mamdani approach because we are discussing Mamdani approach first.

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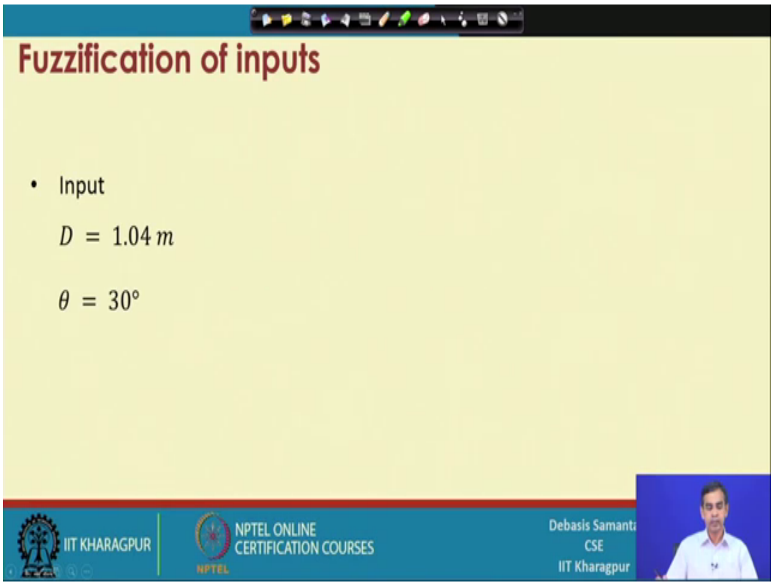

Now first will discuss about the fuzzification input, fuzzification input as we have already discussed that for a given input that is usually the creeps input and then how this creeps input can be converted to the fuzzy input.

Now, the system that we are discussing in these application is a mobile robot and we have already mentioned that mobile robot has the two input namely the distance and then the angle angular direction of a moving object. So, here let us consider for an example at any instant the distance from the robot to a moving object as an input and this is the input and angular direction; that means, in which angle making an object moving towards the robot and let it be theta and theta is value at the current time instant is 30 degree.

So, these are the two input then these are the two input will be given to the controller as a creeps input. So, fuzzy controller will transfer this input into the fuzzy output. So, we will discuss how the two input, these two input can be converted to the fuzzy input.

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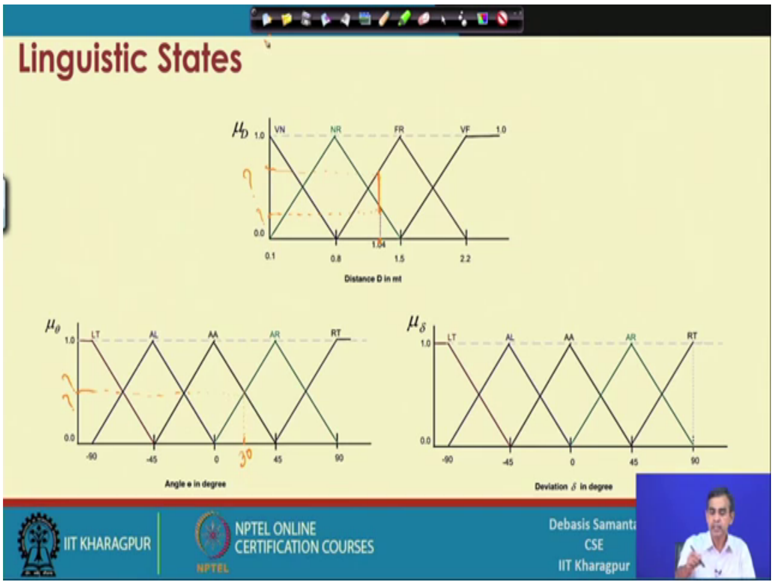

Now, in order to understand how these fuzzy how the creeps input can we convert the fuzzy input we can take the care about the membership function for 8 fuzzy linguistic state that we have already discussed. So, for the fuzzification of the system is concerned and there we can, we call we have discussed two and 3 membership function the other two for the input and one for the output for the input we have discussed about that distance as a 3 fuzzy linguistic 4 fuzzy linguistic namely very near, near far and very far. And similarly for the angular direction we have considered five fuzzy linguistic left, ahead left, ahead, ahead right and then right. So, we have to take the fuzzy input in terms of these fuzzy linguistics.

Now, for an example here as you have considered D is 1.04 this is the creeps input. So, so for the distance is concerned and so for the fuzzification is concerned, D 1.04 is this is the element and this element has the two fuzzy states namely near and far because it cover both the things. So, this means that that creeps input 1.04 as the distance can be considered fuzzily in terms of two fuzzy values the fuzzy near and then fuzzy far. So, distance 1.04 has the fuzzy membership belongs to the fuzzy state NR and 1.04 also is a fuzzy member belongs to the fuzzy state FR, but they belongs to the two fuzzy sates NR FR with certain degree of membership values. So, we have to calculate the degree of membership values for these two elements which belongs to NR and FR.

Now, first 1.04 being the distance and if it belongs to fuzzy state NR then the membership value can be decided by these; that means, this is the membership value is this one. So, we have to calculate what is the value this one. Similarly if you consider the FR fuzzy state distance also belongs to the FR fuzzy state then. So, these membership value this one. So, 1.04 creeps input belongs to two fuzzy state NR and FR having the two dif me different membership values for NR this one and for FR this one and you have to calculate these two values first.

Likewise angular rotation angular rotation that we have considered in this example that theta is 30 degree. So, theta is 30 degree mean this one 30 degree. 30 degree being the creeps input has the two fuzzy states one is ahead and then ahead right. So, if it belongs to ahead then the membership value can be computed this one. So, this is the value that we have to know. Similarly if it belongs to ahead right then it has a membership value the same here in this particular case only. So, these two membership value needs to be calculated and then finally, output will be considered that will be discussed later on.

Now, let us see how the input, but input values the fuzzy values with their membership can be calculated. So, this can be calculated, this can be calculated for example, fine.

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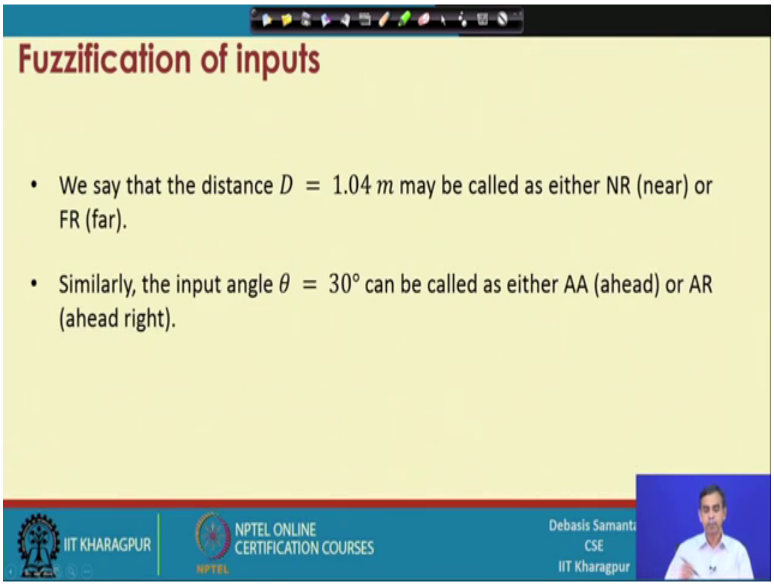

So, we can understand that the D distance 1.04 can be called either NR or FR; that means, they belongs to the two fuzzy state with different membership values similarly the angular orientation theta 30 degree can be called as either ahead or ahead right with the different membership value and we are in the process of calculating the membership values of the their there.

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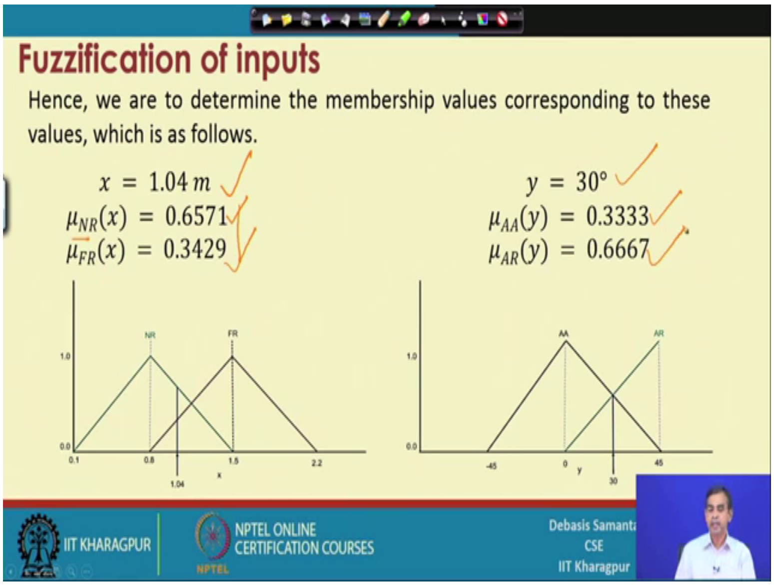

So, here is an example how the membership values for the two inputs one is distance and another is angular orientation can be calculated. So, it is a calculation, calculation shows that the membership values for the distance x equals to 1.04 which belongs to the fuzzy state NR can be calculated as this one. Similarly the membership values for the input x which belongs to the fuzzy state FR can be calculated this one. Likewise the membership values for the other input y equals to 30 degree which belongs to the fuzzy state AA can be calculated as like this and AR can be calculate this. Now, question that is how this calculation obtained.

So, this calculation can be obtained using similarity of triangle and it is very straightforward calculation. So, let us see how this calculation can be calculated here.

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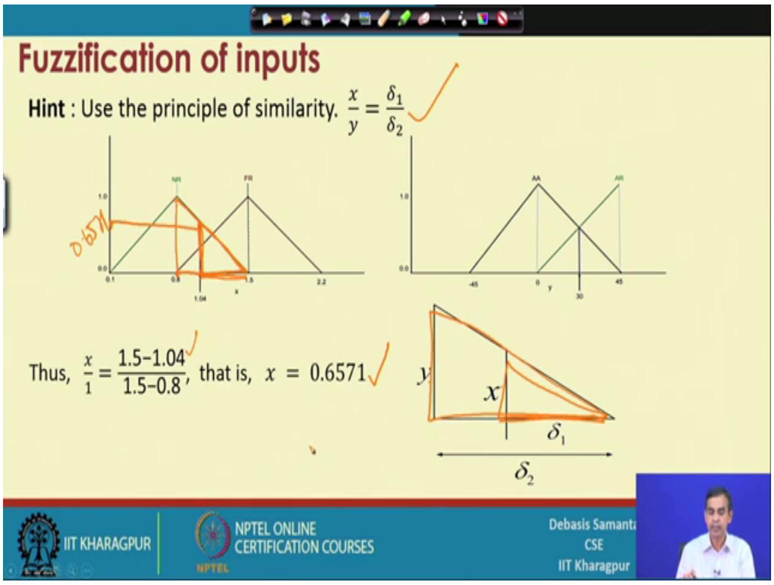

So, idea of this calculation is given like this. So, it basically follows the principle of similarity. Now principle of similarity means if you consider, this is among triangle and this is another triangle. So, these two triangles are similar triangle if they are similar then we can write x by y is equals to delta 1, if this is the delta 1 and if delta 2. So, it is a formula that we have from the principle similarity of two triangles we can follow this one now the same logic can be applied to calculate the different membership values for example, here if you consider distance 1.04 as the input and we want to calculate, these membership value NR right. So, we can consider this is the one triangle and the entire triangle they are similar triangle.

Now, if we considered this things then for this it is basically these values 1.5 minus 1.04 and divided by then this value basically 1.5 minus 0.8 and then if we considered this is basically x and this is the one. So, it x by 1 is equals to 1.5 minus 1.0 this one. So, this way x will be calculated this one. So, x means it is basically this is the x it is calculated this one. So, this value is basically 0.6571 in this case similarly for the angular orientation theta we can calculate likewise. So, it can be calculated like this. Now fine, I just forgot one thing more. So, this is for near. Similarly for FR also we can calculate. So, if we calculate the FR then we should take this is the triangle similar to this is another triangle. So, using these two triangle similarity we will be calculate this value. So, these value can be calculated the 0.333 that we have already learned about it.

So, this is the way that the value can be calculated and the same approach can be extended to calculate the membership values for other input theta equals to 30 degree we can follow this is the one similar triangle and this is one similar triangle to calculate this is the value and if we considered for the AR we have to considered this similar triangle then this similar triangle so that we can calculate this one. So, both we can be calculated and the result can be obtained. So, the result that can be obtained is shown here, so the result that can be obtained that can be obtain easily and then can be used for the next what is called the next step.

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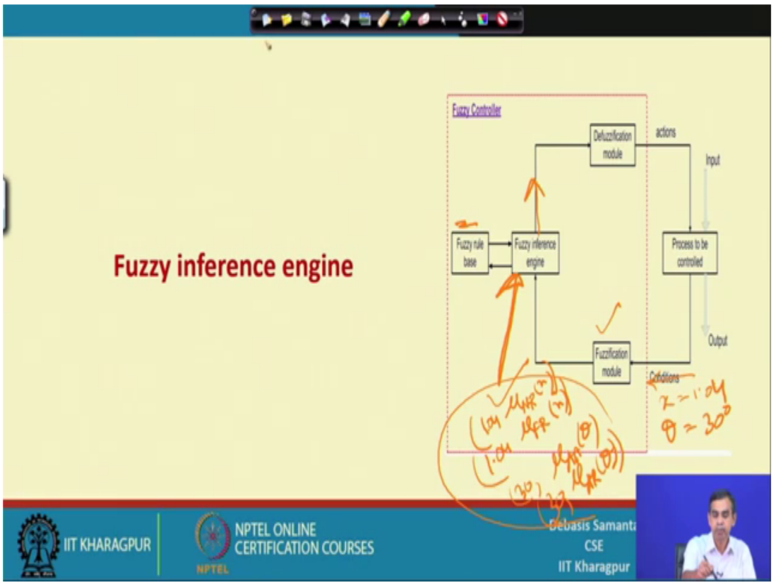

Now, our next step, what we have learnt is the fuzzification module given an input. So, for x equals to 1.04 as the creeps and theta equals to 30 degree the two input and fuzzification module will give you the different mu NR x mu FR x similarly mu AA, theta and then mu AR theta. So, these are the value; that means, 1.04 for read this is the one fuzzy element 1.04 is the fuzzy state and similarly 30 degree is a fuzzy state having the membership value 30 degree is the fuzzy state having the membership value. So, all these values will be used as an input to the fuzzy inference engine. So, these value will be used to the fuzzy inference engine and then fuzzy inference will use these values and cancel the fuzzy rule based and then produce an output this is called the fuzzy output.

Now, will discuss how the fuzzy inference engine take care these values and cancel the fuzzy rule based and produce a fuzzy output that is basically the idea about fuzzy inference engine and will discuss how the fuzzy inference engine can be implemented using Mamdani approach.

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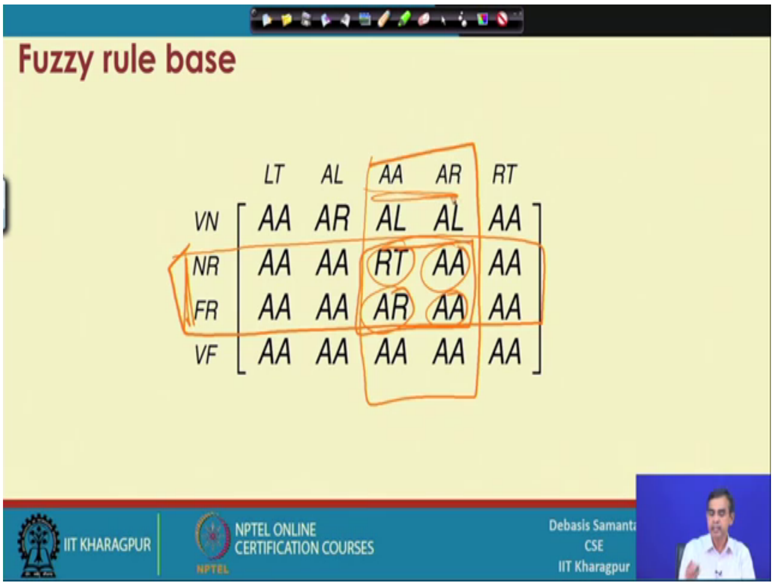

So, the idea is that fuzzy rule base is here that we have already learned and in our fuzzy rule based in the context of current mobile report example we know that 20 rules are there. All the rules are defeated here in the form of a rule matrix. So, out of these 20 rules we have to decide particularly fuzzy inference engine will decide which are the rules are exactly useful, so for the current input is concerned. That means, out of 20 rules all rules may not be applicable in the current context. So, fuzzy inference engine will take a calculation which basically try to see out of these 20 rules how many subset of rules those are basically related and can be considered to calculate the fuzzy output.

So, that is the objective of this fuzzy inference engine. So, fuzzy rules those are the 20 rules we have discussed about it that can be considered here.

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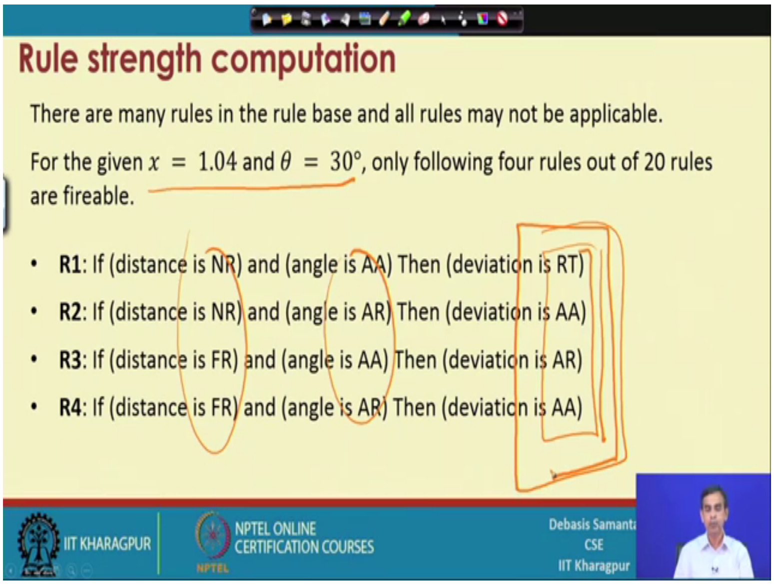

Now, one thing you can understand here that in the current context again we see out of this 4 linguistic only near and far are the important. Similarly out of the 5 linguistic states related to angular orientation only these are important. Now if you consider then, so then intersection of these things means only these 4 rules are basically important; that means, if x is NR and y is AA then deviation is right one rule if x is NR and y is AR then deviation is AA another rule, if x is FR and then y is AA then the angular deviation is theta AR and if x is a FR and then y is AR this one. So, out of 20 rules in this particular context depending on the states so far the distance and then angular orientation is concerned only 4 rules are irrelevant. So, these 4 rules we can display here least here. So, these are the 4 rules that we have just know identified if distance is NR and angle is AA then deviation is RT and so on. So, these are the basically 4 rules that is relevant in the context of current input.

So, at any instant fuzzy logic controller will receive this input fuzzyfy it, these are the fuzzyfy it values and based on this fuzzyfy it basically decide what are the rules that can be favourable and then it will see that these are the most relevant or significant rule, so for the decision of output is concerned. So, fuzzy inference engine will take care about it take an input and then select the subset of rules which are relevant and then it does more in fact, it basically out of all the rules it can take care all the rules and then decide the output. But to be an accurate and then more efficient it will try to find some rules which is already selected or shortlisted here so that it can be more accurate and that is why out of these 4 rules again it apply to rank them and then decide which are the rules are mores strong. So, it basically Mamdani approach is the next step in the inference engine needs to basically compute the rules strength of the selected rules.

Now, how the rules strength can be computed I have given an idea just I will like to give an idea about it.

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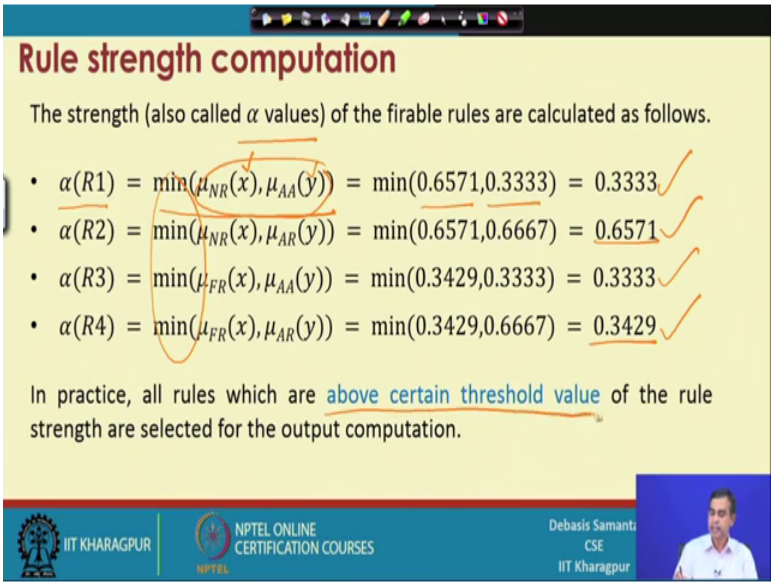

So, it basically calculate is very simple approach to calculate the strength of each rule and this is denoted by call alpha values. So, if R 1, R 2, R 3 and R 4 are the 4 rules the alpha value can be calculated like this it basically take the minimum of the fuzzy membership values for the input. Now, in the context of first rule the two membership values related the fuzzy state NR and the fuzzy state AA having x element are the input and then we have already known the membership value of this. So, it will take the minimum of the two membership values at the rules strength.

Now, in the current context the mu NR x can be calculated as this one and mu AA y also calculator 0.33. So, it taking the min, it gives the rules strength of the first rule likewise rules strength for the second rule can be calculated this one and this one and this one is taking the min of the different membership values belongs to the different states corresponding to particular input. Now, out of these 4 rules then its selects right some rules which are basically based on some threshold value.

Now, if we take the threshold value is 0.300 then all rules will be selected now if we select on the other hand the rule strength is 0.3400 then only these rule and these rule will be selected. So, it depends on the threshold value and the threshold value will be decided by the fuzzy engineer from his own experience or using trial and error method anyway. So, some threshold value is required, in order to select again from the shortlisted rules, so fuzzy engine fuzzy inference engine take a value of a threshold value and then based on this threshold value it will compute the rules strength and then based on the threshold value from the rules strength it select the stronger rule which is basically above the threshold value.

Now, if we consider for an example say rule strength the threshold value is 0.3400 then the rule that will be selected shortlisted is there , if you consider threshold value is 0.3400 then this rule will be ignored, this rule will be ignored only this rule will be considered.

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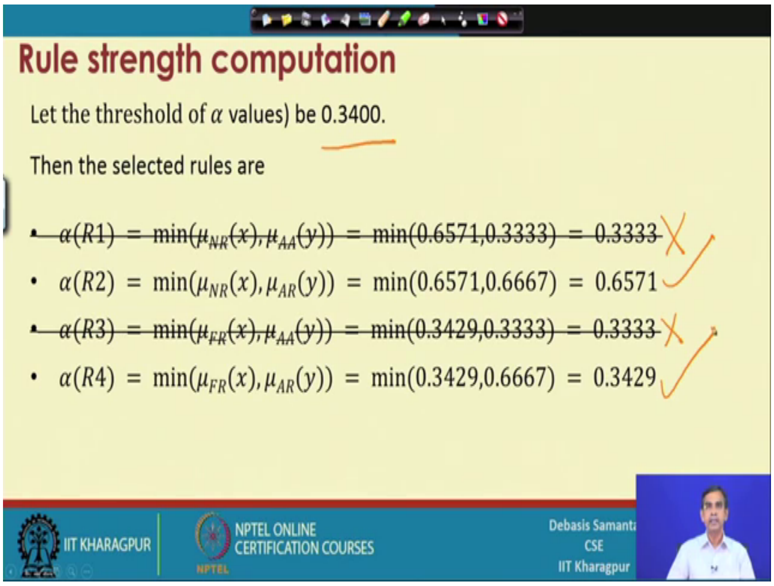

So, out of the 20 rules because of the relevancy we have selected 4 rules and then again by means of rule strength computation we have shortlisted from the list of selected rules two rules only. So, these two rules will be used to calculate the fuzzy output. So, this is the task up to the fuzzy inference engine fuzzy inference engine concern the rule based for a given input and then select the rules according the relevancy and from the relevant rules it again compute the rules strength and based on the rule strength computation and threshold value we select the final list, a final rules those are basically will be used to calculate the input no output of the fuzzy system.

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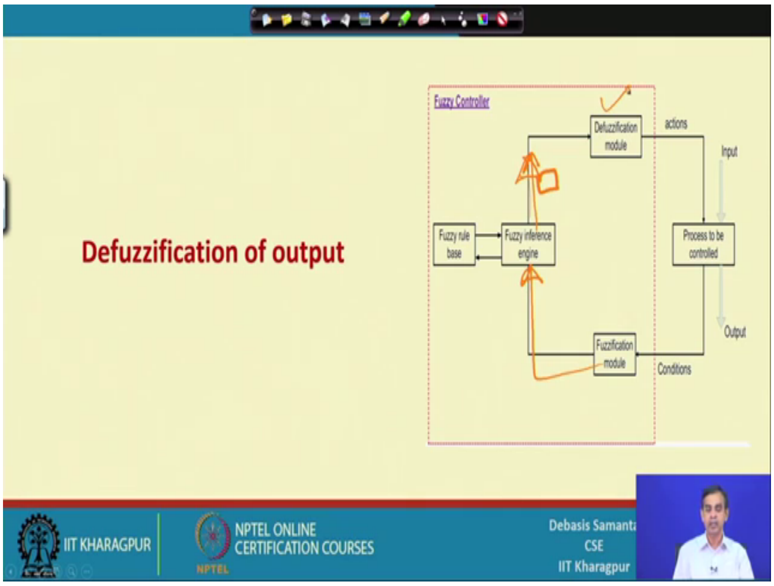

Now, our next task, fuzzy inference engine basically take the input fuzzy input and then produce the selected rules these selected rules basically gives us the output. So, we can say the fuzzy inference return the selected rule, the strong the strong rules and then from this strong rules we can have the fuzzy output. Now, will discussion about how the fuzzy output and corresponding defuzzification of this output is there. So, these the final stage of the fuzzy a logic controller defuzzification of the output and will discuss this fuzzification, defuzzification method in the next few slides.

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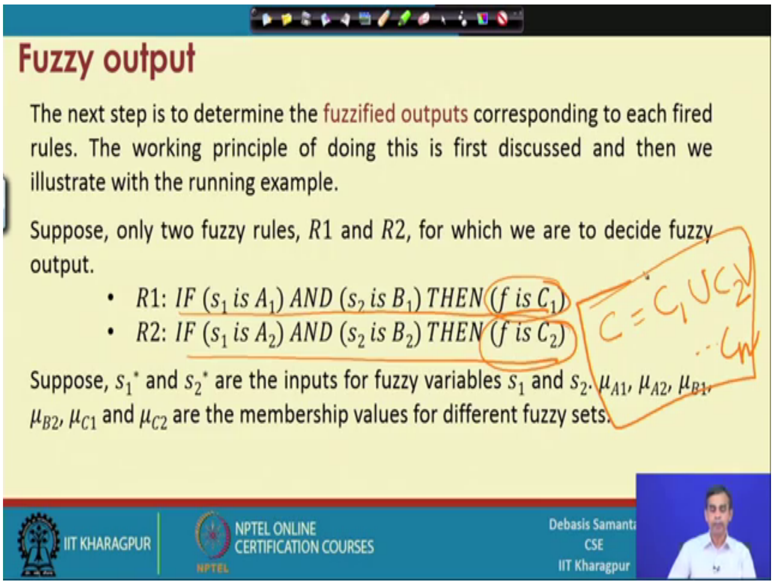

Now, the idea is that that fuzzy inference engine returns some rules those are more appropriate. So, for the decision is concerned corresponding to some input. So, these rules are basically essentially the output for an example. So, suppose is just any two rules are like this. So, this is the one rule and these are two rules. So, output of this rule is basically C 1 that is the output and output of this rule is C 1 C 2.

Now, if we combine the two outputs then the result and output C is basically union of the two output C 1 and C 2 that is the idea that is followed in Mamdani approach there. If there are more rules other than two rules say they are N rules then it will take the union of n output that is there and so output for the system it is basically in a fuzzy way it is the fuzzy output. So, it is like this now in our current example. So, that there are two rules you have selected if x is NR and y is AA, then delta is AA that kind of things are we have considered. So, the output is there.

Now, we will see exactly how given such a rules the output can be calculated.

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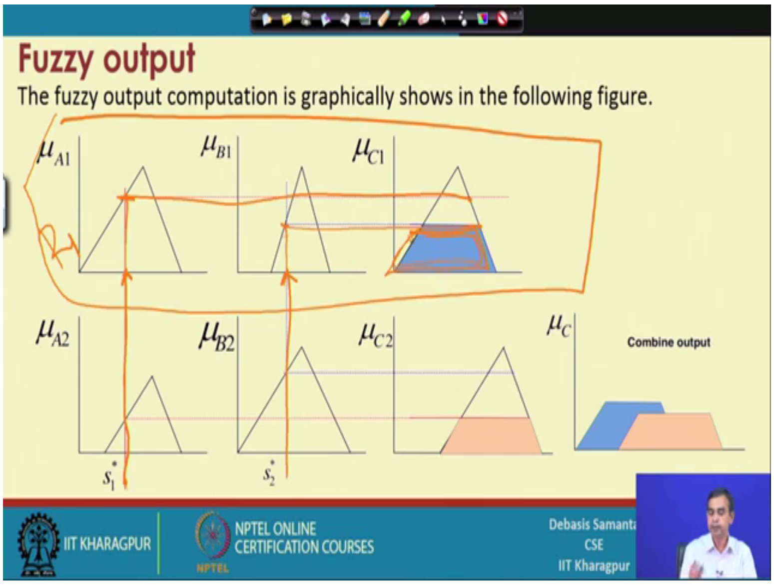

We will, although given example of graphical method, but the same thing can be done in a mathematical way which you have already discussed while we are discussing about defuzzification concept using centroid method or maximum method or waited minimum method or whatever it is there. So, will consider, any method can be applied here. Now, let us see how the output of a fuzzy system based on the different rule can be computed.

Now suppose this is the rule one this is the rule one and then graphical representation of the rule one it basically says that if mu A 1 for an input and if this is the fuzzy state and if mu B 1, for an input and this is the fuzzy state and this is basically the output of the fuzzy state. So, for particular values of input, it basically take, this is the basically input and for another input is there. So, two input are like S 1 and S 2 and then these are the basically rules there are this is the membership value for the first input and this is a membership for the first that we have already calculated. Now, if we draw a line joining this thing and parallel to the horizontal axis then it cut this one and if you like this and this one.

Now, these are the basically output, for the input is concerned, this is the output and. So, for the input is concerned this is output. So, Mamdani approach say that out of the two output you take the minimum of the two. So, these are the two output correspond the input this one and this one and we taking the minimum of this. So, this is a result and output so the rule one is concerned. If this is the rule one, for the rule one this is the output. Now, similarly for the rule two again these are the input corresponding the fuzzy state and these are another input for the another fuzzy state and if we take the minimum of these two then this is the minimum there. So, this is basically the output C 1 and these basically the output C 2.

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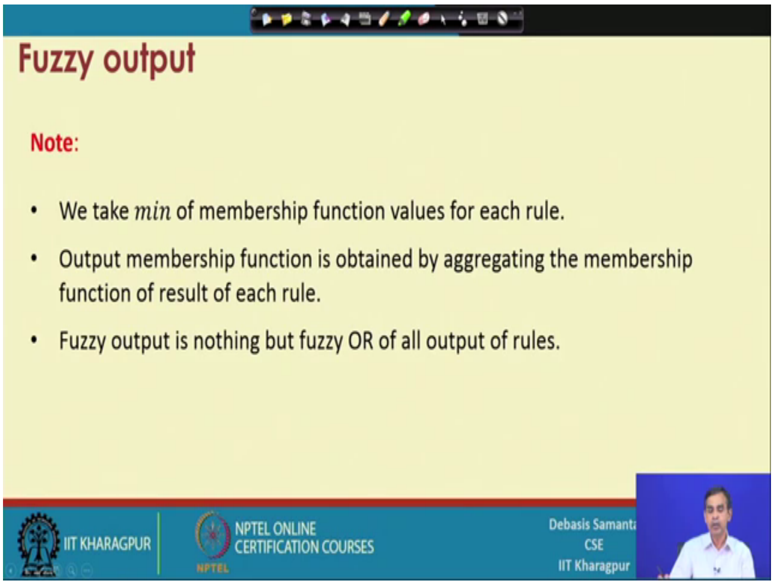

So, if we plot both the output on to the same graph the resultant, resultant output will look like this which is shown here. So, this is the resultant output.

Now, that defuzzification of these output can be obtained either reasons COG method or COS method and will be able to obtain the creeps output from this one. So, now, let us see how in the context of mobile robot we can have the data here. So, they are will consider the 4 rules approach right in the last example that we have consider only two rules I will consider of 4 rules that we have so shortlisted there.

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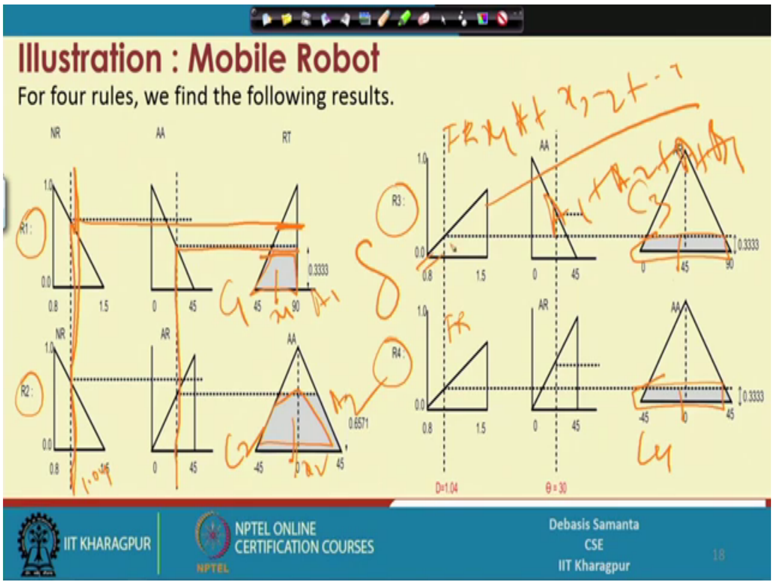

And then how the 4 rules for an example two rules can be considered then it will be most simple I want to give an example with the 4 rules that have been shortlisted based on the relevancy R 1, R 2, R 3 and R 4. Now, let us see how the output can be calculated now here this is the basically input. So, far the distance is concerned and this is the input. So, far the angular orientation is concerned and this is the output regarding the orientation here RT and AA.

Now, if this is the distance x and it will cut the value there for this is for the NR and this is this is for NR for the rule 1 and this is for the NR for the rule 2 and this is basically distance on 0.04 for the rule 3 and this is distance NR for the rule 4. So, it is basically NR and this is basically FR, this graph is for FR, this is for FR and this is for FR and this is the angle of orientation like this. Now again, rule 1 if we fair with x is equals to 1.04 right it will basically cut this one and take the value. So, this is the membership output that is further rule. Now, if you take another input theta then it basically cuts here and this one. So, taking the minimum, this is basically the value of the output for the rule R 1.

Similarly, value of the output for the R 2 can be obtained as this one. So, so for the rule 3 is concerned value of the output will be this one. So, for the rule 4 is concerned value of the output will be this one. So, for 4 rules we got 4 output C 1, C 2, C 3 and C 4 now from this 4 output we can calculate the fuzzy. So, from this 4 output fuzzy output we can calculate the creeps output value that creeps output value can be calculated using COG method or COS method. If you follow COS method for example, we take this area and the middle value take this area and middle value, take this area and middle value take this area and middle value, and use the equation that x 1 into A 1, if it is x 1 it is A 1 the area, if it is x 2 and A 2 and x 3 A 3 and x 4 A 4 and then formula is x 1 A 1 plus x 2 A 2 plus dot dot dot dot divided by A 1 plus A 2 plus A 3 A 4. So, this will give you the output. So, delta value, this way it can be calculated.

Now, let us see what is the results that we can have based on the calculations COG the method. In case of COG method all the output can be plotted on the same graph, this, this can be plotted on the same graph and then from the result and graph we can apply the COG method calculation so that the fuzzy output can be calculated.

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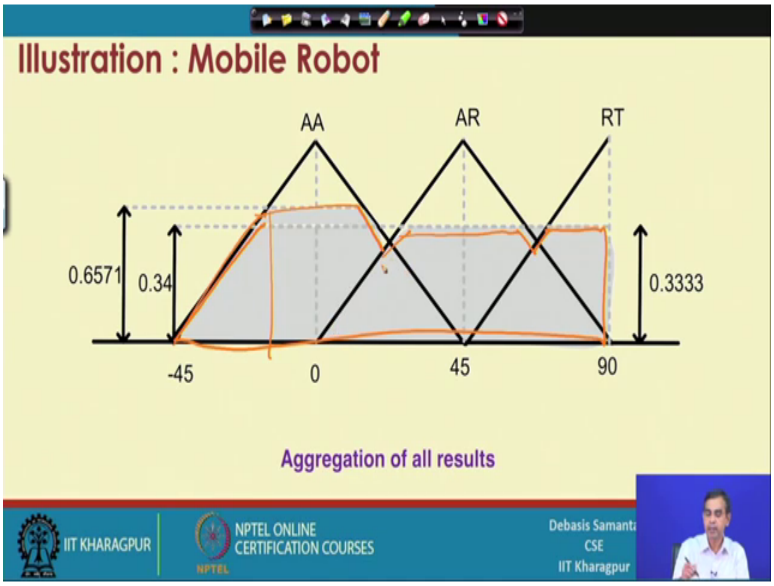

Now, I can give an example here for example, if we plot the 4 different output into the same graph the graph will look like this. So, it is basically this is the graph than this graph then this, then this, then this, then this. So, this is the output graph actually for the 4 rules related to the input x and theta, x is 1.04 theta is 30 degree.

Now, the value can be calculated using COG method is a segment and whatever the method it is there will be able to calculate it that calculator is little bit combustion here. So, if it is the calculation is too much difficult for the COG the method then we can follow COS method of summative new method whatever it is there now using the COG method for the same thing the result that can be calculated is shown here and that is basically the defuzzification.

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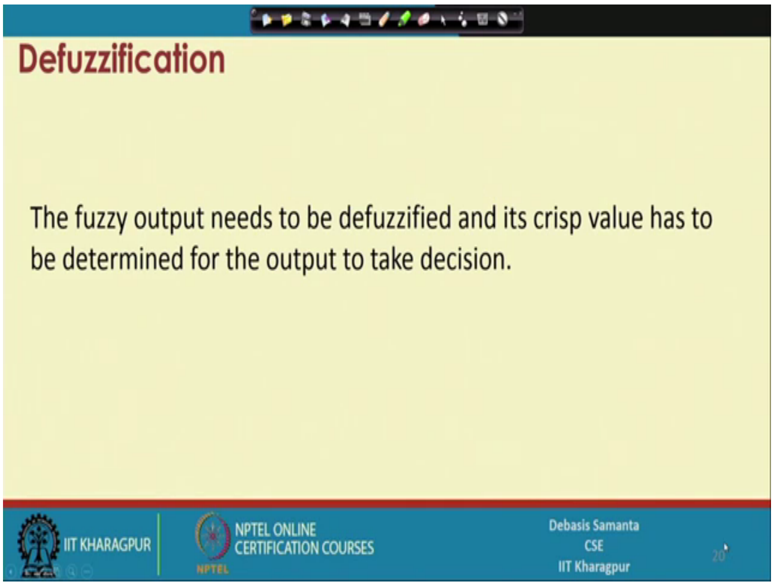

So, fuzzy outputs needs to be defuzzified and the creeps value has to be determined for the output to be taken. In this current context in the current context, this is the input here this is the input and this is another input and then output is basically delta regarding that in which direction it should move.

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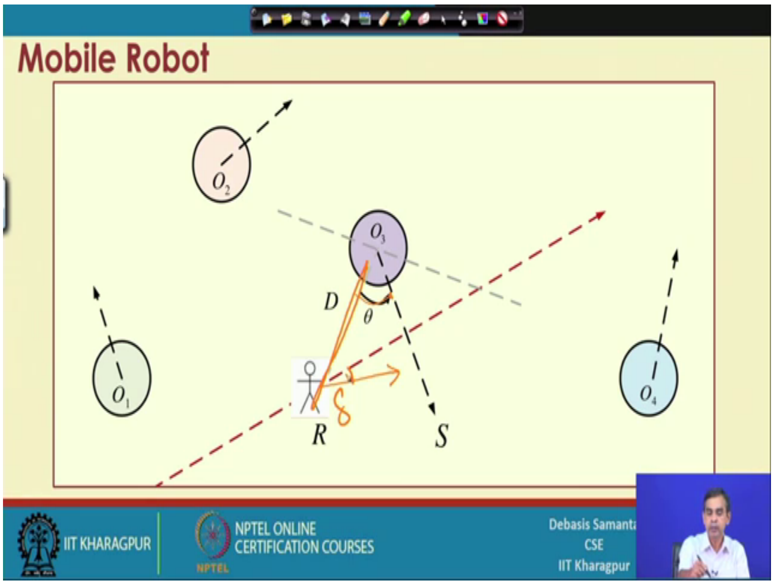

So, that basically obtained by the fuzzy output and then corresponding the creeps value if we follow it can be obtained the result.

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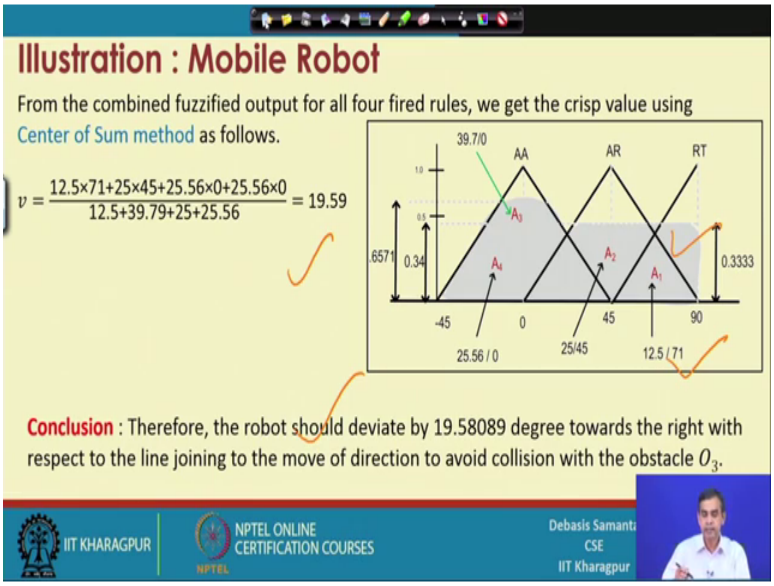

Now, so far the current example is concerned the result that can be obtained using some COG method here we have apply the COG method like and it can be calculated as this one 19.59 or 20 degree. So, this means that the robot that has at the current instance seeing an object this is the seeing and object a current instance seeing an object right it will basically move to the right a positive because this is a positive value to the right as a angle with respect to 3, the 30 degree 20 degree that is the angle. So, that fuzzy logic controller will take a decision about that. It has to do it from it state path towards the right by 20 degree.

So, this output then can be given to the process controller and process controller will take this input and then accordingly controller will move or change the path of the robot. So, this is the one example that we have discussed about it. So, for the fuzzy logic controller is concerned and we will discuss next, another logic controller design that is Takagi Sugeno approach and in our next lecture we will follow that Takagi Sugeno approach in this regard.

Thank you.