Introduction to Soft Computing
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Lecture - 11
Fuzzy logic controller

So, we have discussed about how the different operations related to fuzzy elements can be carried out. Now, we are in a position to discuss about these are designing a complete fuzzy system. Now, the fuzzy system that we are going to discuss is very popular in fuzzy application, fuzzy world and this is called the Fuzzy logic controller.

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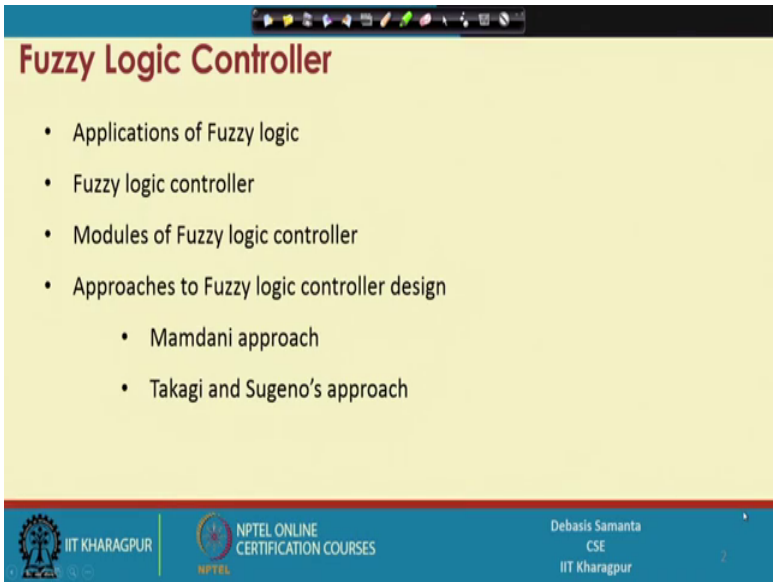

So, actually we are going to discuss about how a fuzzy logic controller can be can be designed and so for the fuzzy logic controller design is concerned they are broadly two approaches are known the first approach is called Mamdani approach and the second approach is called Takagi Sugeno approach.

So, we will discuss about the two approaches in the first we will learn about Mamdani approach and then in the next lecture we will discuss about Takagi Sugeno approach.

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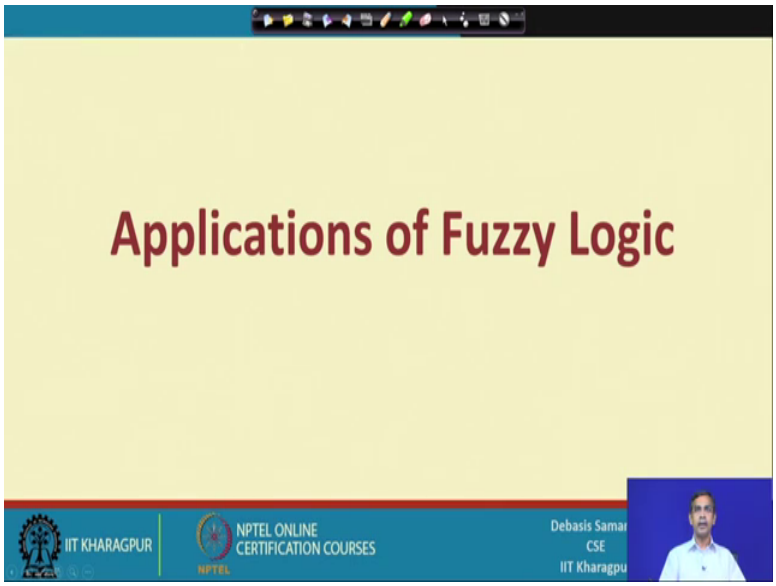

Now, first we have to understand about that what are the different applications of the fuzzy logic. So, there are many applications of the fuzzy logic.

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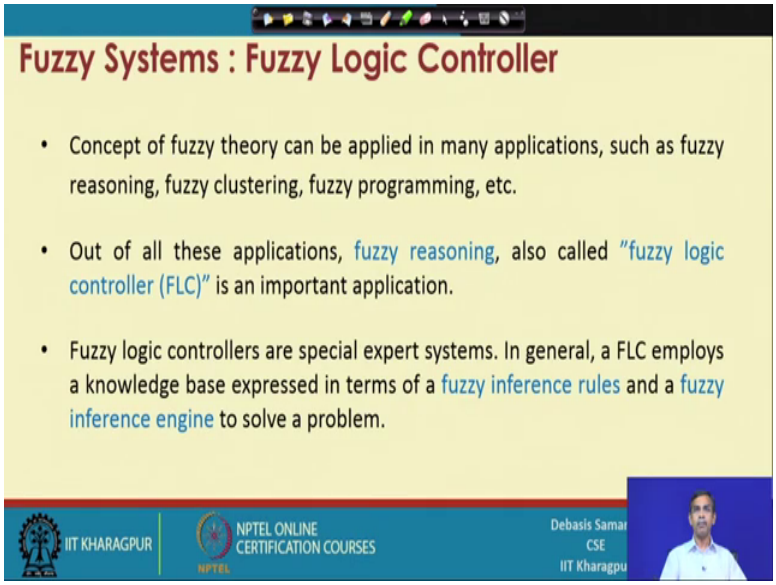

Few application that I have mentioned here one example is called a fuzzy reasoning, another is called a fuzzy clustering, fuzzy programming and so many. Now, out of these application fuzzy reasoning this is also alternatively called as fuzzy logic controller is a widely used on application.

Now, fuzzy logic controller are the type of expert system is a special expert system we can say in general it employs a knowledge based or we can say fuzzy rule base and this fuzzy rule based is expressed in terms of a set of fuzzy inference rules and the fuzzy inference rule is used by one engine it is called the fuzzy inference engine to solve any problem. So, far the fuzzy logic controller is concerned or designing a fuzzy logic controller is concerned the most important task that we have to carried out is that how a fuzzy rule based system can be developed and then how the fuzzy inference engine can be built on that fuzzy inference rule or fuzzy rule base. So, will discuss about these two things, first we will discuss about.

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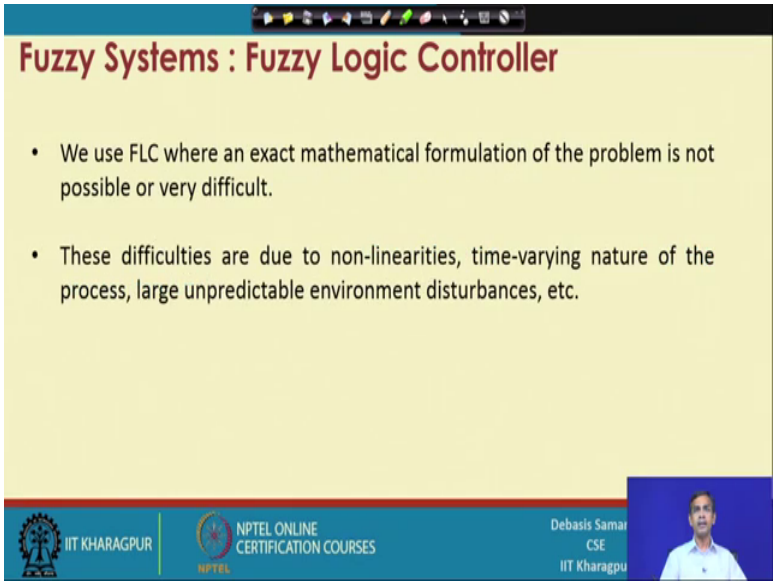

So, obviously, there are few problems where exact mathematical formulation of the problem is not available or is very difficult because of the many uncertainties are there. So, uncertainty may be due to non-linearities in the input; that means, the input does not vary with linear relation or it is a time varying or different time it varies the values or it has lot of noises due to the environmental disturbances. So, the value is really unpredictable at a time. So, if these are the situations having the input then we should follow the fuzzy system to develop and to solve this kind of problem.

So, fuzzy logic controller is one example here and we will see exactly how such a fuzzy logic controller can be developed.

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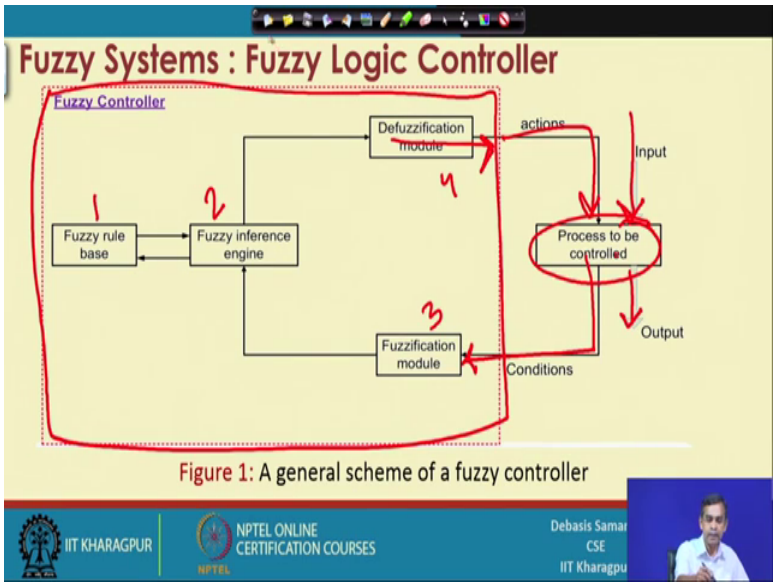

Anyway, for the fuzzy logic controller is concerned this diagram basically saw the overview of a fuzzy controller system and if we see it carefully. So, the fuzzy controller this is the portion of the fuzzy controller right and this is basically an external interface with the outer world. So, these are the basically fuzzy world and this is basically the crips world we will come into this portion later on.

Now, in this fuzzy system you can see there are 4 basic tasks involved. So, the first is fuzzy rule base, second is fuzzy inference engine and third is fuzzification module and finally, fourth is defuzzification module. So, these are the tasks if we can plan it then a fuzzy system can be developed once this fuzzy system is developed any input that is basically crisp input can be given to some controller; that means, the controller means it is basically the controller which will control with the 8 of fuzzy controller actually and it will take any input and this input will go to the fuzzy system as a conditions it will process it and then it will give an output which basically the crips output after defuzzification and this will be as an action. So, process will get output then this is the output that is has to be followed.

So, this is the basic idea about the fuzzy logic controller and we understood that there are mainly 4 different what is called the parts here the parts are fuzzy rule base and then fuzzy inference engine, the fabrication module and defuzzification module.

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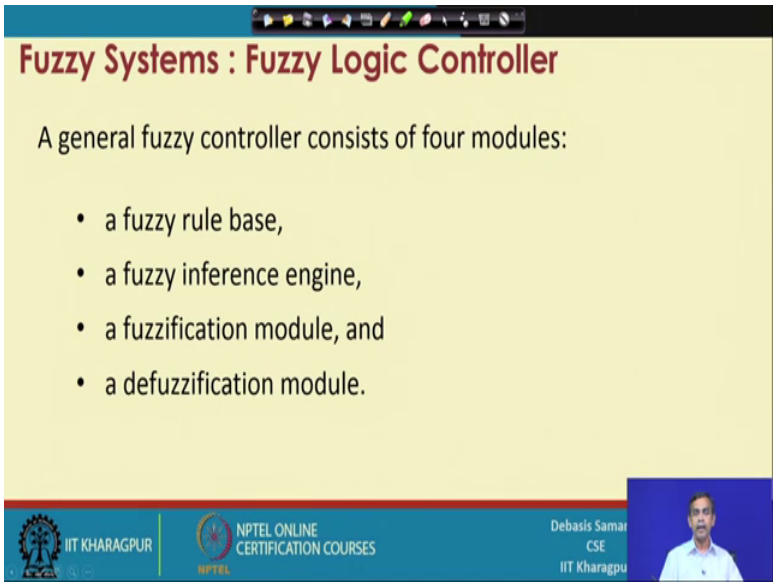

So, for the fuzzy logic controller or a fuzzy system reason is concerned we have to just design these 4 components then system will be built up.

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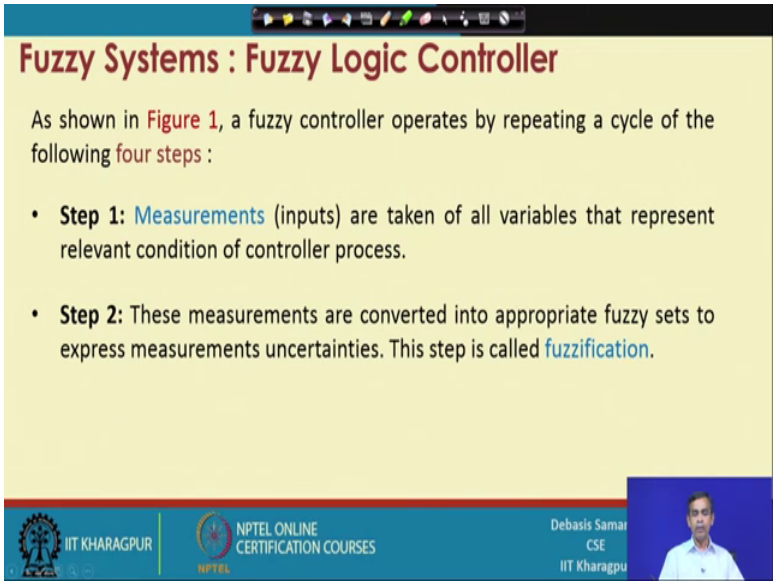

Now, I will just little bit a brief detail about the different processes involved. So, for the fuzzy logic controller is concerned it is basically a cyclic process it will take an input it will decide what exactly the control to be decided producing output take another input and output, is a cyclic method.

Now, we can consider on say AC, AC to be control if we change the temperature if we change the humidity these are the inputs suppose and then fuzzy logic knows exactly with the different temperature and different humidity what the output. So, far the motor rotation is come some it will produce an output we go to the motor rotator and then output will take this value and rotate accordingly. So, this way AC can be controlled air conditioned can be control like. So, this is an example.

Now, here the different steps that is involved there are mainly 4 steps in case of the first steps we have to take the input that is basically called a measurements it is basically for a system there may be one or more input. So, definitely we should consider all inputs taken together and that can be considered the condition to the controller process and then these measurement which is basically an input to the system is a crisp value. So, this needs to be fuzzified.

So, this second step is called the fuzzification and then one the major input is taken and it is fuzzified the second, the third step is basically all these fuzzified inputs are to be used and then pump to the inference engine. The inference engine will basically evaluate what are the control rules to be followed that is basically they are in the fuzzy rule base.

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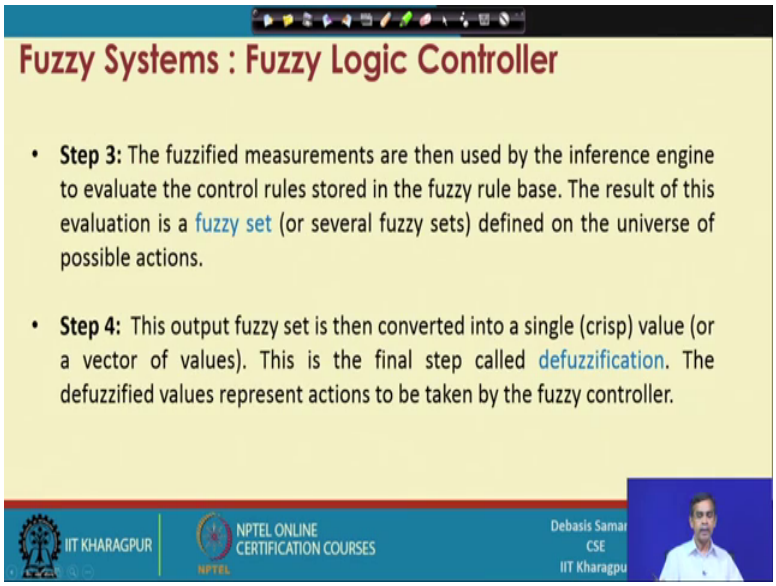

The result of this evolution basically all provides a fuzzy set or maybe a several fuzzy sets and then output of fuzzy set or fuzzy sets can be considered and then taken as the output of the overall system. The output that we have obtained it is basically in terms of

fuzzy set or fuzzy sets then we can convert the corresponding fuzzy set or fuzzy sets into a crisp value or set a vector of crisp values and this is called the defuzzification. So, these are the 4 steps that is involved in case of fuzzy logic controller.

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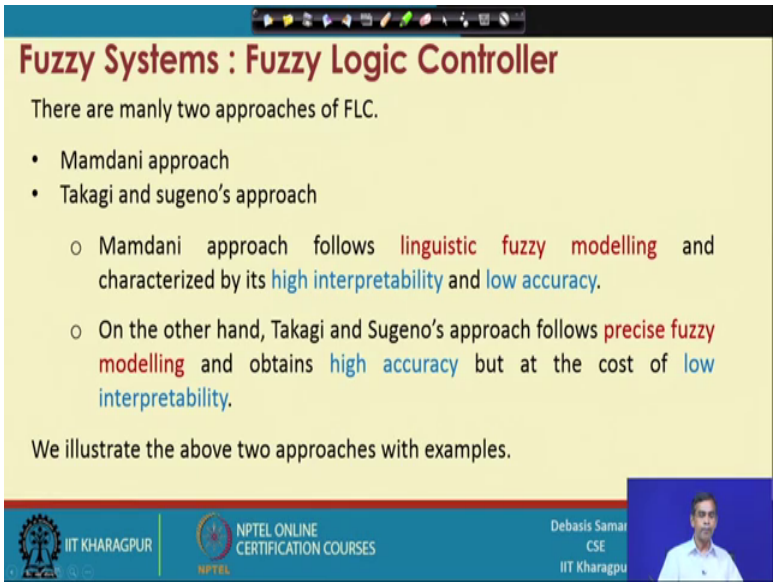

Now, let us come to the approaches there are two approaches I told you one is called a Mamdani approach and another is Takagi and Sugenos approach. Mamdani approach basically the simplest and more popular approach it is simplest because it is highly interpretable; that means, if we see the system we can or any lemon also can interpret. This is the concept of the system; however, it provides a little bit lesser accuracy compared to the Takagi Sugenos approach.

And this model the Mamdani approach basic follow the linguistic fuzzy module; that means, all the fuzzy sets should be available to us some in terms of some linguistic states. On the other hand the Takagi and Sugeno approach it follows precise fuzzy modelling it is more numerical than the linguistic fuzzy modelling that is used in Mamdani approach. In fact, compared to the Mamdani approach provides better result; however, it is low interpretable; as it is mathematically little bit expressed, so interpretation is bit difficult for the general user.

Anyway, we will discuss first, will discuss first Mamdani approach and then the Takagi Sugeno approach with some case studies. So, that we can understand the concept it is there.

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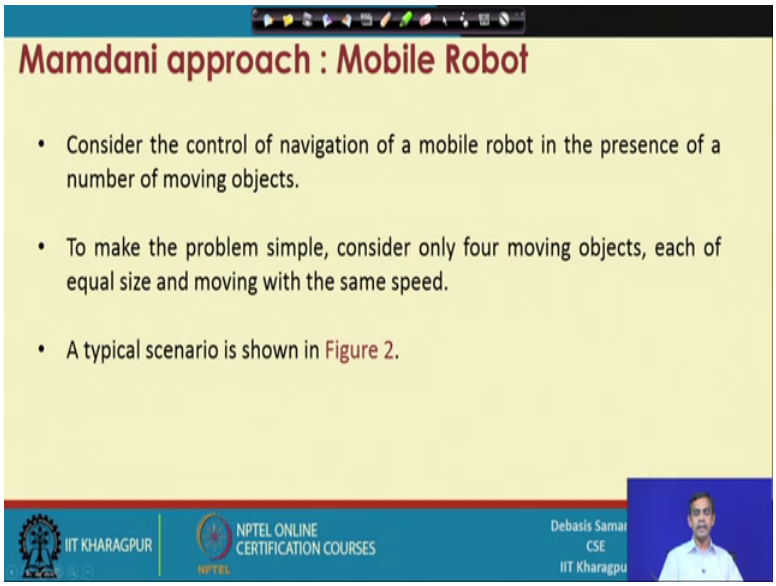

Now, we will discuss the first Mamdani approach and to discuss the Mamdani approach will consider an example it is basically movement of robot we can say it is the mobile robot. So, the problem here is a robot has to move in presence of several objects that is available there. So, robot has to move in such a way that it should avoid the collision and all the objects are not necessarily static objects they are also moving. So, it is a basically problem at any instant mathematically we do not know which path needs to be followed. So, path can be followed with lot of uncertainty or lot of variation in the non-linearity of inputs or time varium input and so this is a critical problem and this problem really very difficult to solve a simple programming approach.

So, we will see how such an application can be developed using some fuzzy theory, fuzzy logic. Now, a typical scenario of the mobile robot I want to give it fast and we have to discuss with certain assumption, assumption these that the robot has to move in precents of 4 moving objects and we also assume that each objects are of equal size and all objects those are they are moving with the same speed. However, this is a simple assumption so that we can discuss it and then learn it, but these assumption not nestled to be followed in actual movement of the mobile robot consideration. So, anyway so that is an extension of this.

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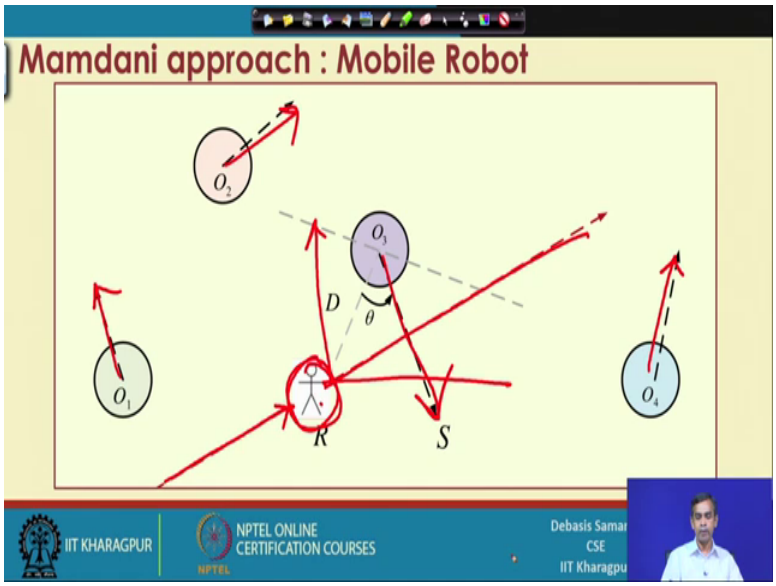

Now, this is the one simple display of the scenario of a particular instant and here assume that this is the robot has to move, and there are 4 different objects O 1, O 2, O 3 and O 4 in the vicinity of the robots at any moment robot is moving here in this direction and the different objects moving like O 1 is moving along this direction, O 2 is moving along this direction, O 3 is moving along this direction, O 4 is moving this term. Now, at any instant the robot has to take a decision if all these movements are there then which path he should follow, he should follow the same path or he will follow this path or in this path. So, it basically decide that as a next direction of the robot at any instant when he sees the different situation of the objects.

So, input to the robot can be obtained by some means about the different movement of the objects by some camera or whatever it is that is available this one and then it can calibrate and then different objects and his movement can be obtained. So, this is the case and then our task is basically to design a fuzzy controller for the robot so that robot can use this fuzzy controller to take its movement direction at the presence of the different objects around it.

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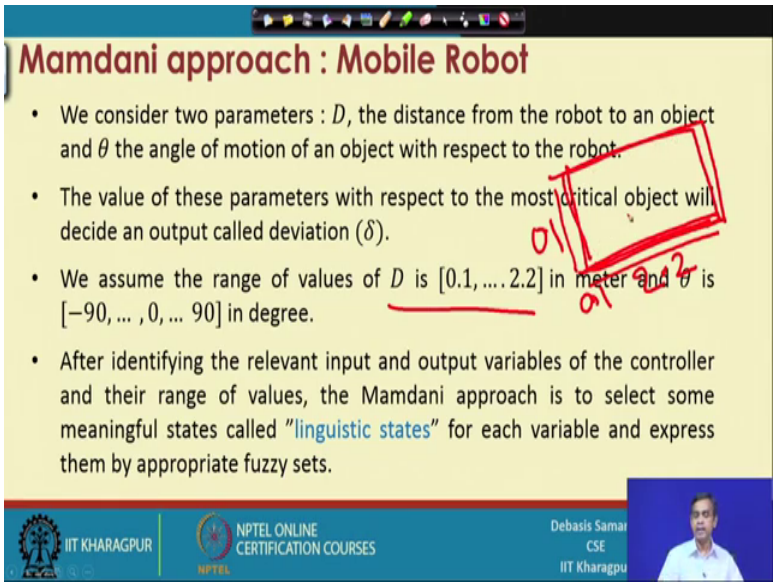

So, this is the application. So, this is the application. So, if we consider if we carefully observe this system we can consider that how the input to the system can be specified and then what is the output is there. Now, here as an input to the robot we can consider two parameters, one is D the distance from the robot to an object and theta the angular motion of an object with respect to the robot. So, these are the two input that can be used to the fuzzy logic controller for the robot to decide it.

So, for the output is concerned we can decide one output it is basically called the deviation; that means, from the step from its own line how much deviation can be there. Now, here we will consider the first input D as this one here this means basically this basically signifies the total area of the movement of the robots; that means, it will start from the location 0.1 and 2.2 horizontal white and vertical whites. So, it is like this. So, this is the 0.1 and this is at 2.2. So, this is the area along this one and this is the size of this one and this one. So, this is the total area. So, it is 0.1. So, 0.1 and this is 2.2. So, this is the area total by which the robot moment will be restricted.

So, considering this is the D; that means, range of values of the D that can be available like this and then the theta the rotation; that means, the angular direction of the different objects we consider in the range minus 90 to 90.

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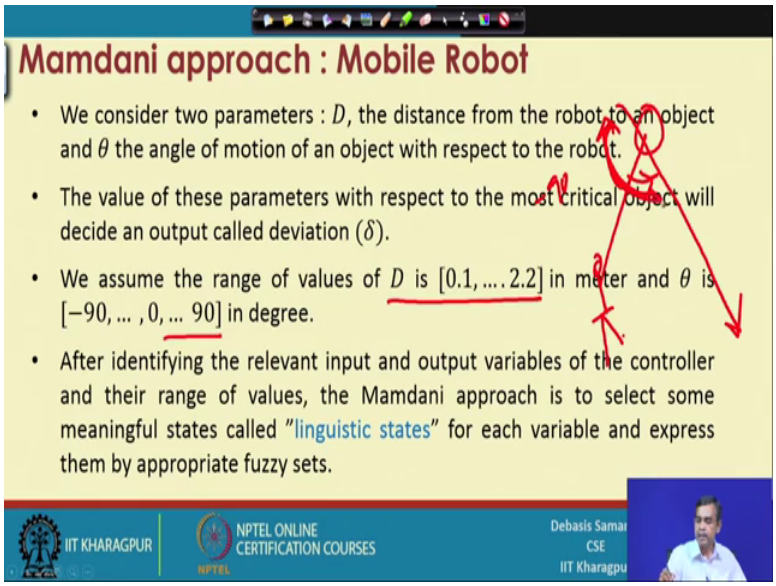

So, if this is the robot and then, with respect to this over the object that can be moved here right, if this is the movement and then according to this with the angle of this one, this can be if it is anti clockwise then it is basically 0 to 90 degree and if it is clockwise then is minus 90 to 0. So, this is the range basically that the robot has to take a measure about an object with respect to this one. So, these are the two inputs and then output also similarly for this deviation will be minus 90 to 90; that means, toward left and toward right according to that.

Now, the fuzzy sets that is required to describe this kind of behaviour and will express according Mamdani approach it basically decides the linguistic states for each input here D theta and then output this one in terms of fuzzy sets. So, will discuss what are the different linguistic states for this particular example can be obtained. So, the linguistic state that can be obtained for this fuzzy set is given here.

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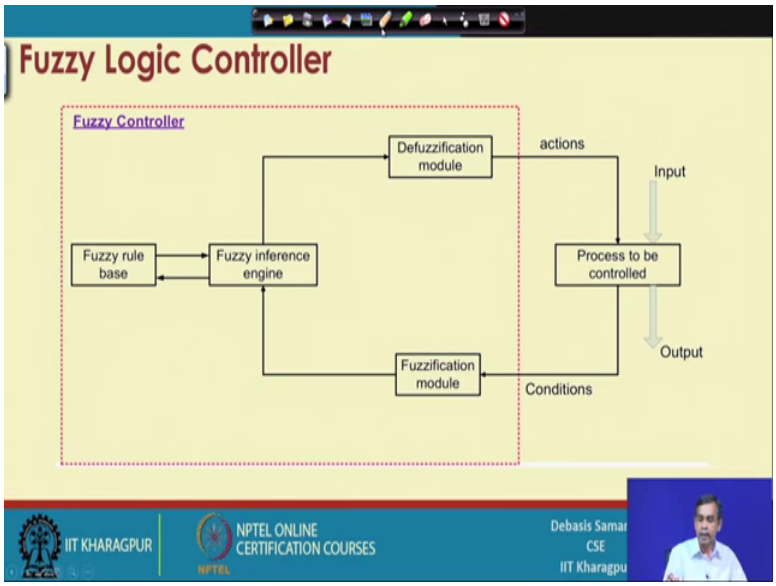

So, anyway we will discuss about first is the, these are the fuzzy controller system as we have already mentioned here first we have to decide about fuzzy rule base. Now, in order to decide the fuzzy rule base we have to fix on the fuzzy linguistic states according to the Mamdani approach. So, first let us discuss about how the fuzzy rule base can be discussed and then we will discuss about fuzzy inference engine.

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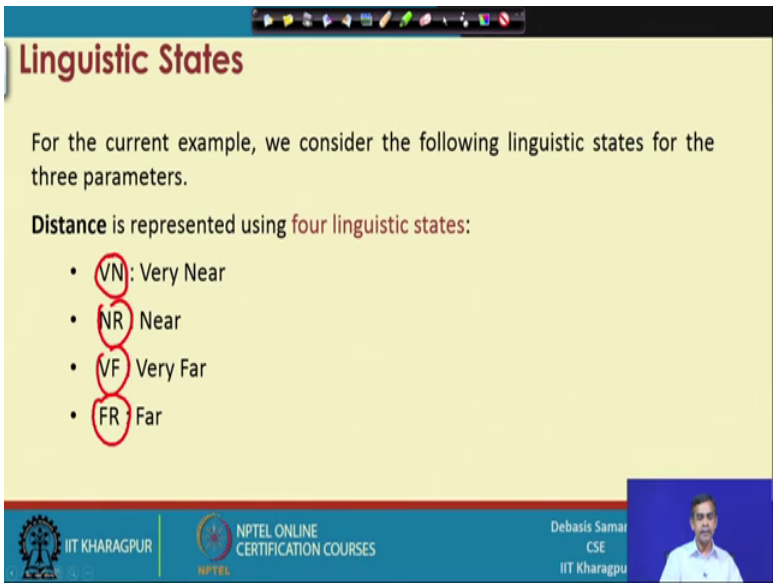

So, for the fuzzy rule base is concerned as I told you we have to first discuss the different input that we have to consider and then output how they can be expressed in terms of

fuzzy sets. So, for this robot mobile robot we consider for the distance D has the 3 the 4 different states; that means, linguistic states they are basically defining the distance as a fuzzy sets we discussed that 4 one is very near denoted as VN, and the near denoted as NR, very far VF, FR far that mean distance can be fuzzily described as very near, near very far and far in terms of the 4 different fuzzy linguistics.

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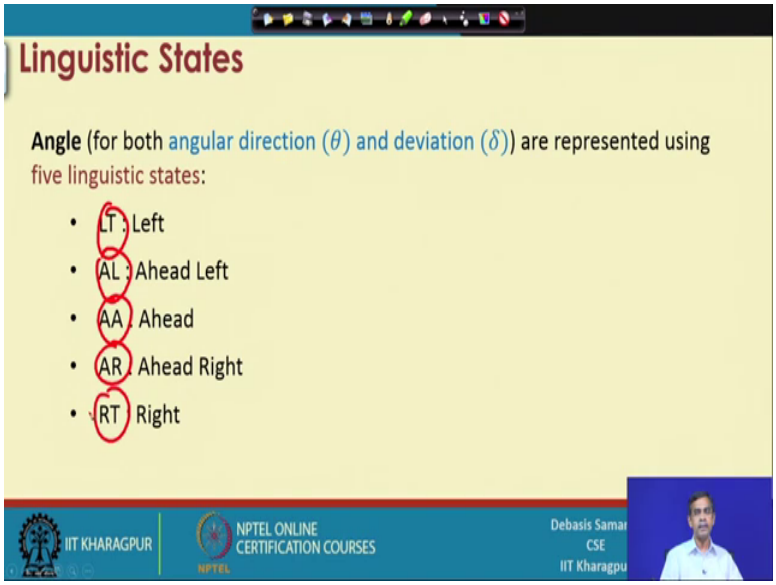

Now, similarly the angle that is the direction of the robots with respect direction of an object with respect to the robot or the deviation of the robot can be describes again in terms of 5 different linguistic states. That we have discussed about here the 5 linguistic states are left, ahead left AL, ahead and ahead right AR and then right.

Now so, it is basically the prerogative of the fuzzy engineer who can disguise that about the particular input and then they can decide the fuzzy 5 states. So, we have discussed for 4 different fuzzy states for the distance and 5 different fuzzy sets for the angle. So, we can discuss alternatively 3 different fuzzy sets for distance also and then 4 different fuzzy sets for the angle or 3 different fuzzy sets angle or more than 5 different fuzzy sets also. So, it depends on the fuzzy engineer how he can plan it how can design it. So, it is totally depends on the expertise of the fuzzy engineer to decide the fuzzy linguistic sets.

And whatever the fuzzy sets you decide it will work for you whether accurately or less accurately that is depends on the design actually. So, these are the, I mean two different inputs the D and theta the fuzzy sets can be defined similarly for the delta also as it is an

angle. So, the same fuzzy linguistic can be considered. So, for the theta the angular direction and for the deviation delta the same fuzzy linguistic can be considered here. Now, after having this one, we will see exactly the rule base. Now, we will consider, we will be able to discuss about the rule base.

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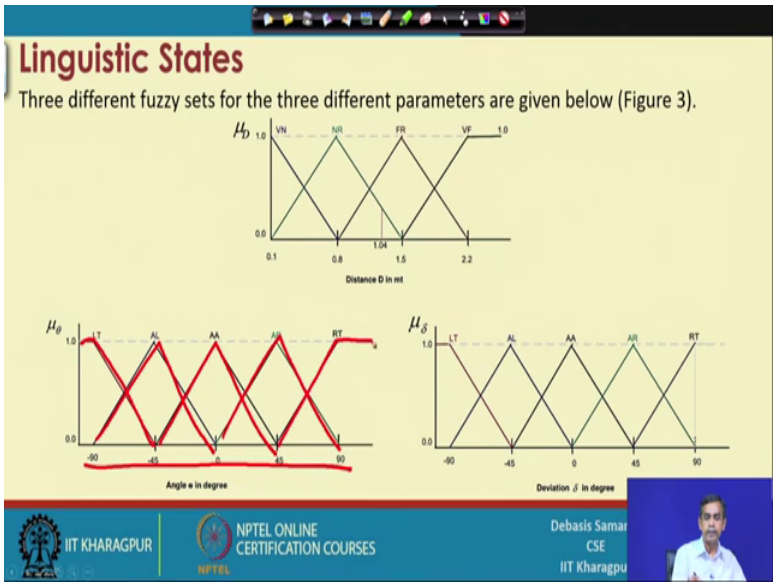

Now, before going to this for each fuzzy set they should be defined by their corresponding membership function. Now, we will discuss about the membership angle we know that the fuzzy membership function can be of either triangular shape or trapezoidal shape or some bale shape like this one.

So, in this example we consider the different fuzzy membership function for the different fuzzy sets namely say distance related fuzzy sets, fuzzy linguistic like very near, near, far, very far using some triangular membership function. For very near the membership function is like this, similarly for the near the membership function is like this and then for far the membership function is like this and for very far the membership function is like this. So, we can easily understand that whether near object is like this, so membership function will vary like this one. So, this has certain meaning with respect to in our fuzzy uncertainty and then the corresponding the fuzzy elements there.

Now, likewise the membership function for the angle theta and then division also can be described. So, as we told you that the value ranges from minus 9 to 90. So, it is basically the range of values that is for the membership function should be and then for the

different fuzzy linguistic like left it is defined here then ahead left it is ahead, ahead right and then right this one. So, this way the fuzzy linguistic and then corresponding membership function is well defined and this is the same thing this is defined for the deviation delta and we can note that for theta and delta their membership functions are same. So, it is quite possible and because angle and then this then derivation they have the similar magnitude and then similar of interpretation.

Now, having this fuzzy linguistics and then fuzzy membership functions we are in a position to decide about the rule base.

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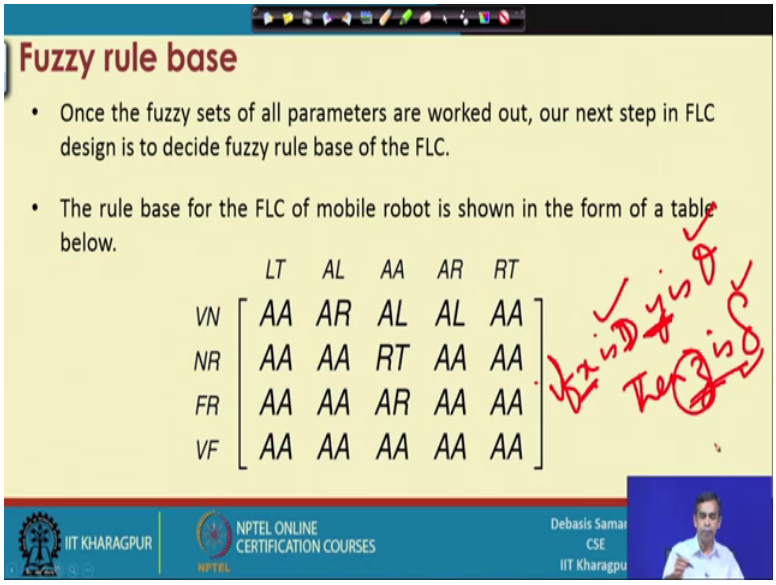

This rule base can be for simplicity we can define this rule based in terms of a rule matrix and here basically the rule base signifies few things that for any particular value that belongs to the distance and for any particular value of theta how the rule needs to be decided. For example, here one idea is that. So, the rule base it is like this as you know rule is taking this form if x is D, D y is theta then z is delta, it is like this, this is a rule like this; that means, if the distance belongs to this one in a fuzzy linguistic and then there a rotation angular direction y is in terms of fuzzy linguistic then what will be the output in stomp of fuzzy linguistic delta.

So, these are the fuzzy linguistic as you have already studied and these are the different input at any moment and then so for this different input how the output z can be obtained. So, this is basically objective and such things can be expressed using some rule

matrix. So, these are rule matrix that is there and in this rule matrix all the fuzzy linguistic sets related to the distance and then corresponding linguistics they relate to the angular direction is row and then column y specified.

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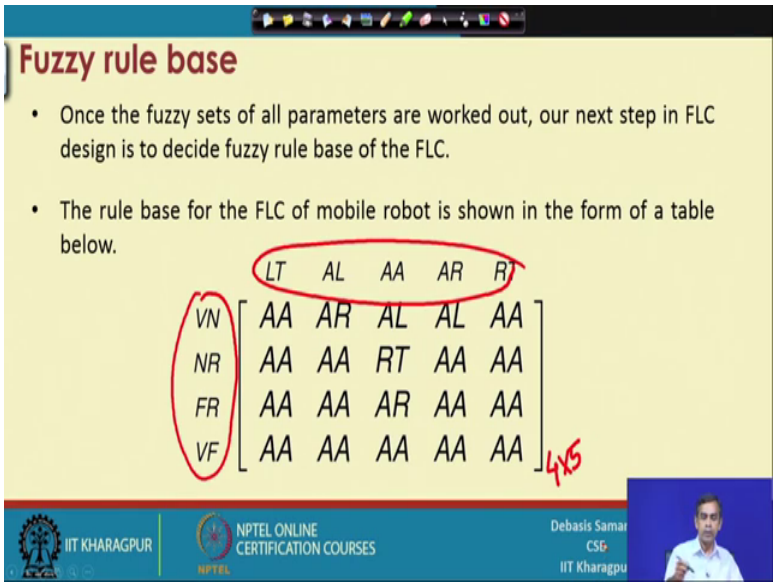

So, here if x is VN and then y AA, it says that see x is VN and y is AA; that means, the angle is ahead then rule this that direction delta is AL that mean deviation will be AL. So, it is like this for example, if this is the one another output; that means, if it is FR and this is the angle direction so that direction will be AR. So, this basically says that different rules that can be fireable they that can be related to the fuzzy movement and this is expressed in terms of rule base.

And here so far the 4 linguistic sets are there which belongs to the distance input and then 5 linguistics are there, so for the input angular direction. So, altogether, the total number of rules that is here feasible these are equal 4 into 5 means 20 rules. So, in this fuzzy system and this basically gives the rule base this is the rule base which is shown in the form of a matrix and we can shown the same rule base in the form of a fuzzy proposition that we have already discussed there; that means, if x is D y is theta then z is this one these are the rule form look like, anyway.

So, we will discuss about these the rule base and you will see exactly how such a rule base can be used and then corresponding inference engine can be developed that is our next target.

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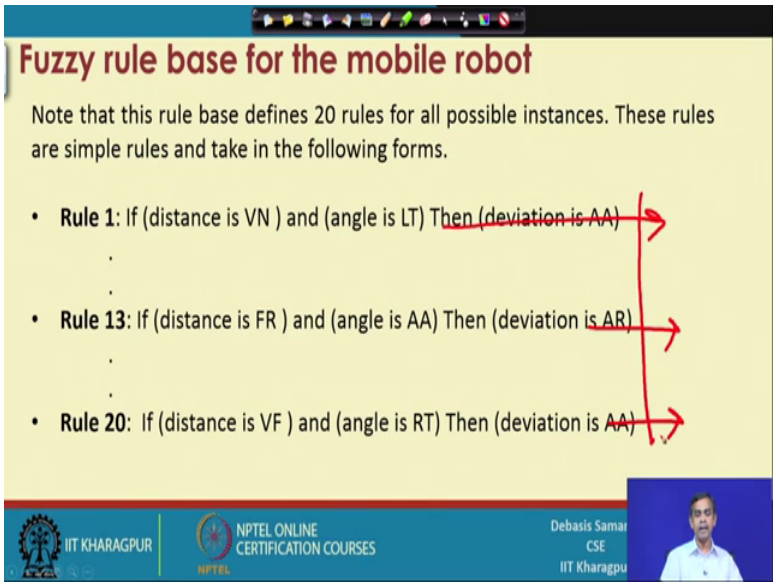

Now, so far the fuzzy rule base for the mobile robot is concerned I have told you. So, altogether there are twenty rules rule one is like this. So, if distance is VN and then angle is LT then derivation is a similarly the other rules are there. So, all rules can be expressed this one and you know such a rules can also be expressed in terms of a rule and what is called a matrix relation matrix sort of thing. We have already learned that how such a rule can be stored in for matrix and all these metrics. So, then we can take all the rules and then corresponding all matrixes and then we can infer something from there that is the rule inference, whatever the idea we have discussed earlier they can be applied here.

Now, in case of Mamdani approach they follow a little bit different idea rather more simplified and then sophisticated idea that is considered here. Now, see here the rule that, so we have learned about the fuzzy rule base just now, we learn about fuzzy; we have learned about fuzzy rule base we have learned about it.

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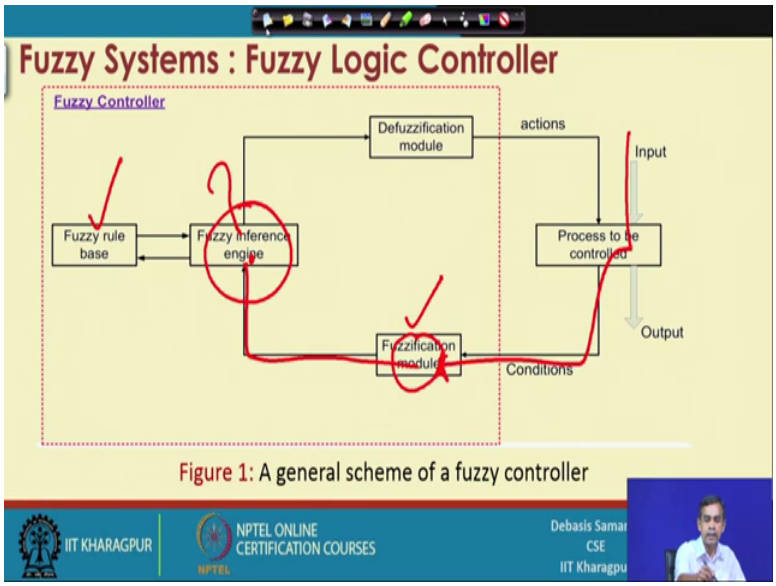

And then we are we are in the process of learning the fuzzy inference engine and before going to fuzzy inference engine basically we have to learn about fuzzification module. So, our next task is basically what will be the fuzzification module is there. Now, fuzzification module basically takes some input and then this input is to go to the fuzzification module, take the fuzzified value and this fuzzified value will be used by the fuzzy rule engine. So, we will not be able to discuss the fuzzy inference engine until we discuss the fuzzification module and so we will discuss about the fuzzification module first.

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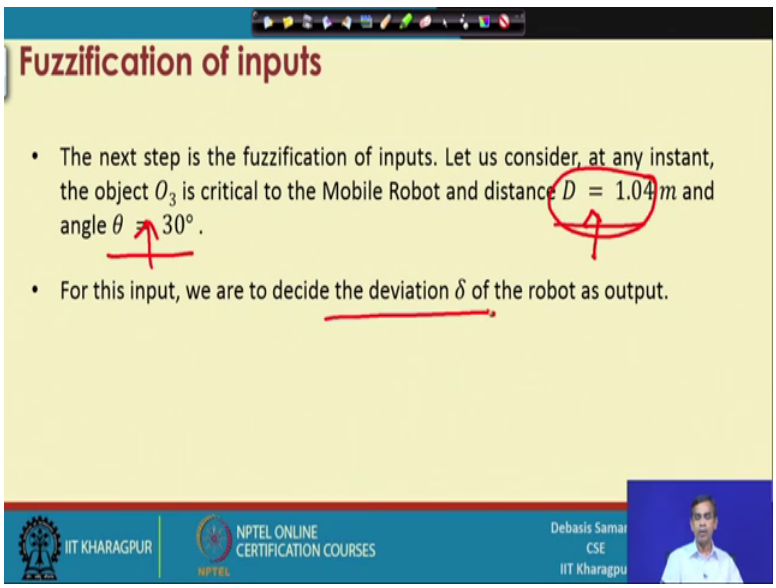

So, for the fuzzification of input is concerned we have to consider a specific instance for a particular values of the input we will consider that at any instant a D that is the distance of the distance of an object from the robot is basically 1.04 meter and obviously, it will be in the range 0.1 to 2.2 that we have already specified there and at that instant also we assume that the angular direction theta equals to 30 degree. So, this is a specific instance and at the specific instance we will see exactly how the these are the crisp value crisp value of the input can be fuzzified in terms of whatever the fuzzy linguistic state that we have discussed their and then corresponding the fuzzy output and then finally, we will calculate that deviation delta of the robots.

So, typically it is basically idea it is like this, so a particular example that I have already told you.

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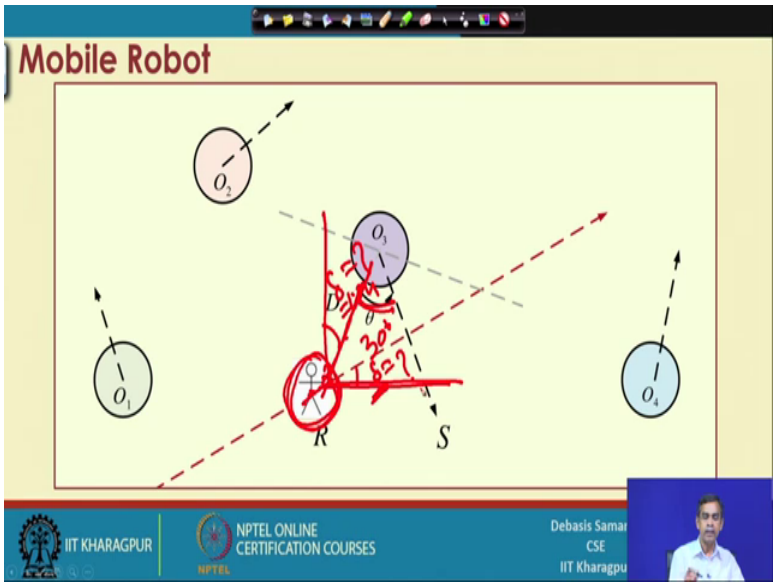

So, it is basically D these is the D and in this case 1.04 and this is a theta at any moment this is 30 degree. Now, here, this is the input that is available to the fuzzy logic controller of the robots and a taking this input the controller will dictate the robots that in which direction either with certain delta here or in this direction delta here that we have to decide. So, this is the likely value that singular value. So, fuzzy logic controller will take this input this D and then theta and then calculate delta and then it automatically the machine that is our tools that is there in the robot it will take this value and then direct the movement according to this direction or that one. So, this is the idea about it. So, our

next task is basically how to calculate the fuzzy input for a given crisp input and, so it is here.

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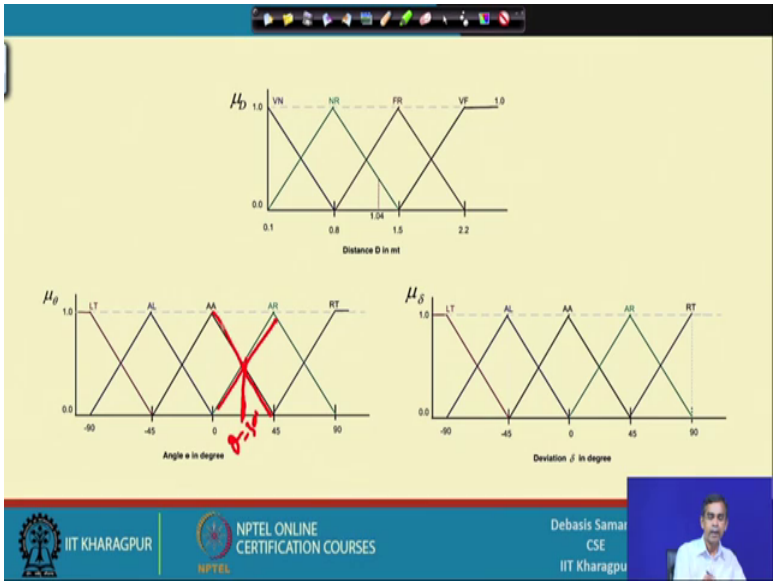

Now, that typically so far the con is concerned here we know that these are the linguistic variables linguistic fuzzy linguistic for the distance and D at the moment is 1.04. So that means, this is the crisp and then corresponding crisp the fuzzy output is it fireable to NR that means so far the near is concerned it is that this value with these a membership function.

Again for the same this is the also favourable to the fuzzy linguistic far; that means, D being the distance 1.04 it belongs near fuzzy set as with this membership value and it also belongs to the FR fuzzy set with this membership value. So, these are the fuzzy input actually you will calculate it and then we will use it. Likewise for theta equals to 30 degree, these are the, both ahead and AR ahead right are applicable to this so far the fuzzy input is concerned. So, if this is the theta equals to 30 degree then course on theta the fuzzy input will be AA and AR.

Now, in the next discussion will discuss about how; in the next we will discuss about how such the procedure general procedure for obtaining for a crisp input the fuzzy output, fuzzy input.

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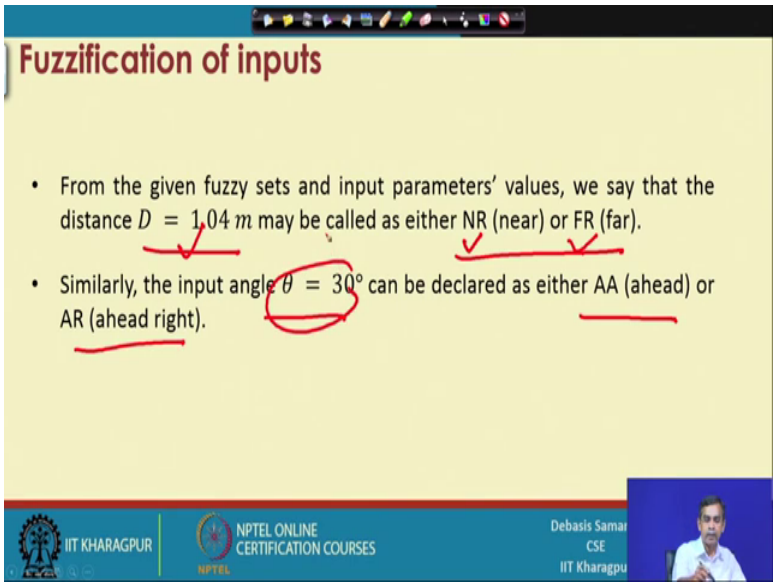

So, in this particular context of example as we have learned it, D 1.04 if it is a fuzzy crisp input then it has the fuzzy output near and FR, but near with certain membership value and FR with certain membership value. We will be able to easily calculate and we will see the calculation in the next lecture how the near fuzzy sets and FR fuzzy sets for this input can be obtained. That is basically called the fuzzy input or fuzzification for the input. And likewise for theta 30 degree which graphically I appear as ahead and ahead right both are feasible and then what is the corresponding membership value therefore, the fuzzy sets that for this input can be obtained. So, all these things will be discussed. So, that will be discussed in our next lecture.

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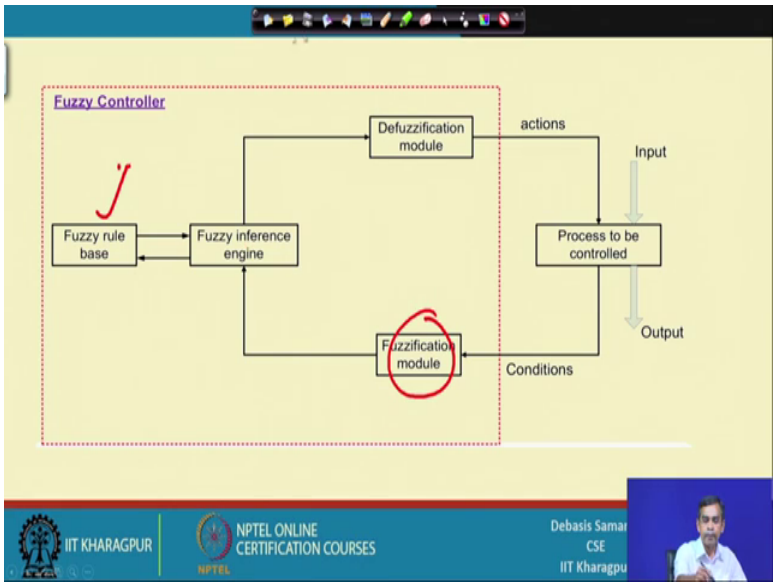

And then, so till time we have discussed about the fuzzy rule base fuzzy rule base design and then we will discuss about the fuzzification module, once we learn it then go to the fuzzy inference engine which will be covered in the next lecture.

Thank you.