Fuzzy Logic and Neural Networks
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Lecture – 39
A Few Applications

I have explained the principles of fuzzy logic and neural networks with the help of some numerical examples. Now, we are in a position to discuss a few applications of these tools and techniques. Now, if you see the literature a huge literature is available on various applications of fuzzy logic and neural networks in different areas the fields like the general science the engineering science commerce and so on.

Now, time is short. So, I will not be able to discuss a large number of applications.

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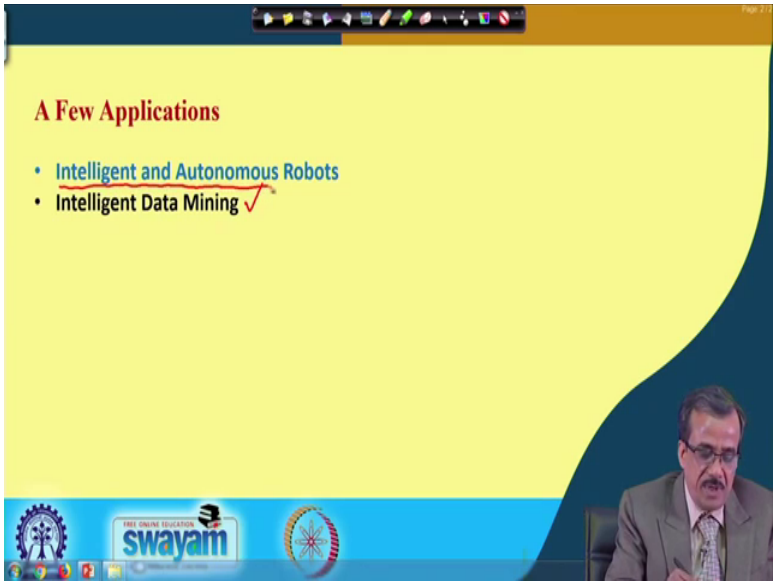
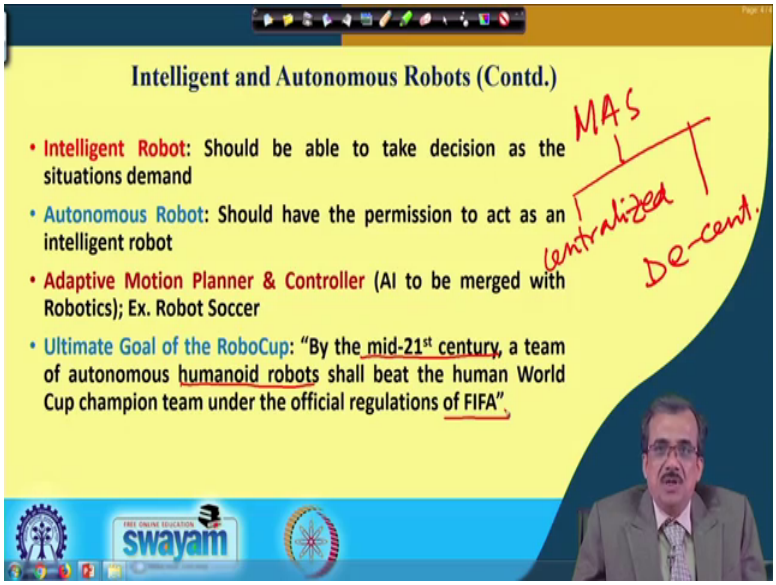


So, what I have decided I will be concentrating mainly on two applications related to intelligent and autonomous robots like how to design and develop intelligent and autonomous robots using the principle of fuzzy logic and neural networks. And then I am going to concentrate on intelligent data mining. So, how to extract useful information from a data set using the principle of fuzzy logic and neural networks. So, let me first concentrate on the intelligent and autonomous robot like how to design and develop intelligent and autonomous robots.

Now, before I start with these particular application or let me tell you one thing. Now, you need not worry if you have not taken any course or if you do not have the fundamental information of robotics. So, the your the fundamentals of robotics is not required. In fact, the thing which I am going to discuss. So, without discussing the principle of robotics. So, I am going to discuss how to make it intelligent and autonomous using the tools and techniques like fuzzy logic and your neural networks. (Refer Slide Time: 02:34)



Now, let us try to see like what do you mean by an intelligent robot and what is an autonomous robot. Now, by definition an intelligent robot is a robot which we will be able to take the decision as the situation demands. Now, this robot could be either a robot with fixed base like manipulator, it could be mobile robots like your the wheeled robots, multi legged robots like six legged robots or four legged robot or it could be even the biped there could be tracked vehicles there could be your drones and so on.

Now, so, if I want to make it intelligent. So, I will have to add a few features to this particular the robot. So, those features I am going to discuss and how to develop those features using the principle of the fuzzy logic and neural networks. Now, if I proceed further let me try to explain what do you mean by an autonomous robot. Now, to start with let me tell you that intelligent robot an autonomous robot there is a basic difference now autonomous robots are those intelligent robots which are having the permission to act in an intelligent way; that means, your all the autonomous robots are intelligent

robots. But all the intelligent robots may not be the autonomous robot. Now, here in these discussion. So, I am just going to concentrate only on the intelligent robot.

Now, to develop this intelligent robot so what we will have to do is so, we will have to design and develop some sort of adaptive motion planner then adaptive controller. And to develop this adaptive motion planner and controller the principle of artificial intelligence that is AI or the computational intelligence that is CI is to be merged robotics. Now, if you see the literature a huge literature is available on soccer playing robots. The main purpose of the soccer playing robots is actually how to design and develop adaptive motion planner adaptive controller for the intelligent robots.

Now, this soccer playing robots actually they will constitute one intelligent robotic system that is called the multi agent system of robotics. Now, in short this is known as MAS. Now, this multi agent system of robotics so, it could be either centralized or it could be decentralized. Now, if it is centralized, then it is having one central computer to control the activities of the different robots different intelligent robots. On the other hand if it is decentralized so, there is no such centralized control all the robots are intelligent. All are agents and there will be activities of these particular agents that is nothing, but decentralized multi agent system of robotics.

Now, here among these agents or your intelligent robots there will be competition there will be cooperation and of course, they are having one goal and that particular goal has to be fulfilled. Now, this particular robotic system is bit difficult and designing a suitable motion planner and controller is bit complicated. Now, if you see you might have heard about the robocup. The robocup is nothing, but a competition or soccer playing robots and the goal of the robocup has been set as follows by the mid twenty first century. A team of autonomous humanoid robots shall beat the human world champion team under the official regulations of fifa; that means, a team of humanoid robots intelligent robots should be able to defeat the world that the cup champion team by following the regulations of fifa. Now, this is not an easy task.

Now, if you want to reach that particular milestone there should be lot of activities particularly how to design and develop the humanoid robots that I am not going to discuss. But once you have designed and developed the humanoid robots how to make it intelligent and if required autonomous. So, that like it can serve the purpose.

So, it can beat your the human world cup champion football team now these particular task as I told is a very complicated one. Now, here what I am going to do is I am just going to take a very simple example and let us try to see how to tackle that particular problem. And if we can tackle that particular problem then with some modification we can also take the problem related to decentralize multi agent system of robotics.

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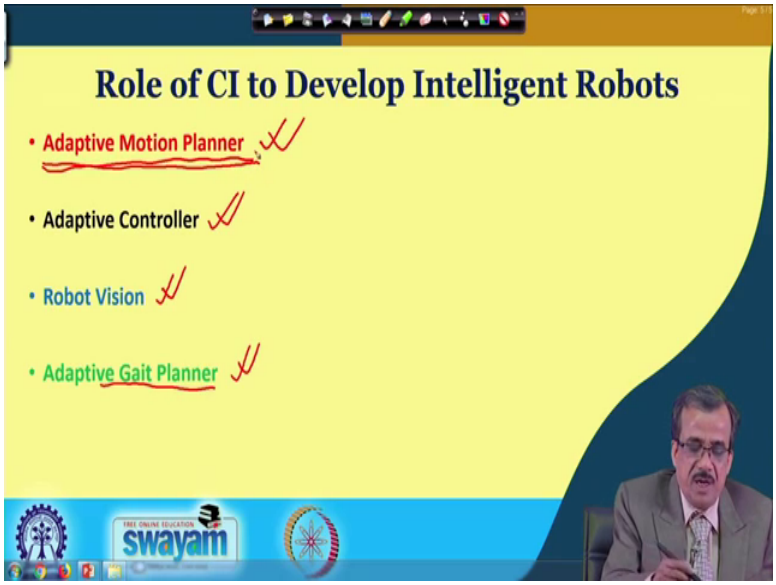

Now, let us try to concentrate on a problem which is very simple I should say like and that is related to how to design and develop the intelligent robots. Now, if you want to make the robot intelligent and if you are planning to use the principle of CI that is your the computational intelligence like these four areas. We will have to concentrate for example, say we will have to concentrate on how to develop the adaptive motion planner. Now, the purpose of the motion planner is to take the decision as the situation demands.

Now, if this is the set of inputs. So, how to find out the decision that is the output decision? So, that it can tackle that particular the situation in a very effective way. The next is your adaptive controller. So, this I am going to discuss in details now at each of the robotic joint we use some motors those are called the DC motors and for each of the motor there will be a controller. Now, I will be discussing in details we generally use like PD controller or PID controller and we can find out what should be the adaptive values for this particular that the gain values that is K P, K I and K D.

Now, then we will concentrate on the robot vision or the computed vision and how to use the principle of fuzzy logic and neural networks. So, that the robot can visualize the different objects lying in the environment and this principle of robot vision and the computed vision. So, I will be give I will be giving a brief introduction and then I will try to find out the regions where we can use the principle of your the fuzzy logic and neural networks to tackle this problem in a very efficient way.

Now, if we concentrate on the biped robot the humanoid robot then of course, we will have to concentrate on adaptive gait planning or adaptive gait generation. So, we will be discussing like how to plan the adaptive gates depending on the environment or depending on the requirement. So, I will be concentrating one after another. So, these particular the problems. Now, let me first start with the adaptive motion planner. Now, this I have already mentioned that the purpose of motion planning is to determine the course of action for example, say if I want to find out the collision free path for a particular robot, the robots should not collide while moving from a particular the location to another location. And to ensure that collision free movement of these particular robot with the moving obstacles say. So, we will have to make some strategy we will have to make some planning.

Now, let us see how to tackle. So, this type of problem. So, we are going to concentrate on how to design and develop the adaptive motion planner using the principle of fuzzy logic and neural networks.

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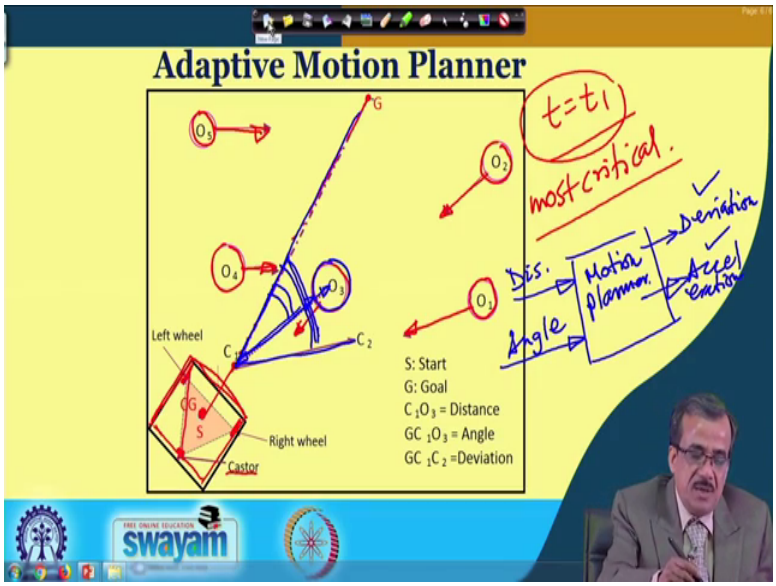

Now, to start with let me take a very simple example of one mobile robot. And this particular mobile robot is nothing, but actually a two wheeled robot. So, this is actually your the robot that two wheeled robot. So, here I have got one wheel, I have got the second wheel here and for support actually I have got a caster here. So, caster is actually one wheel, but it has got no drive unit and supposing that to operate. So, these two wheels say I am using say two DC motors.

Now, let us see how to make a plan. So, that it can avoid collision while moving from an initial position to the final position. Now, supposing that. So, this is the initial position of the robot. So, let me consider the c g of these particular two wheel differential drive robot and supposing that this is the goal for this particular the robot. Now, if you imagine that there is no such obstacle here in this particular environment. So, starting from here and if you say that you try to find out the collision free time optimal path very soon very easily it will try to find out these direction or these path either the collision free time optimal path. So, the robot should be able to reach the goal in minimum time by avoiding any such your the collision, but if there is no obstacle there is no question of collision.

Now, supposing that. So, in this particular environment there are a few moving obstacles for example, say here I have got one moving obstacle say, O 1. Another moving obstacle, say O 2. Then we have got O 3, O 4 and O5. So, here I am just going to consider five moving obstacles and these shows actually the direction of movement. This shows the

direction of movement of these particular obstacle. The direction of movement, these are all direct set of movements ok.

Now, if you want to solve this particular problem the first thing we will have to do is at a particular the time say t equals to t 1. So, I am just going to make the plan. So, I will have to find out the position the predicted position of these particular moving obstacle and supposing that the at time t equals to t 1. Or I am just going to make planning for time t equals to t 1. So, this is the initial position of the robot.

Now, at this particular position so, it will try to find out the most critical obstacle. Now, how to find out the most critical obstacle? To find out the most critical obstacle actually what it will have to do is it will have to find out. So, what is the distance between the robot and your the moving obstacles. So, we try to find out the distance between the robot and the obstacle and at the same time we try to see the direction of movement of these particular the obstacle. So, we decide the most critical obstacle by considering the distance between the robot and the obstacle as well as we consider the direction of movement of these particular the obstacle. Now, supposing that. So, this is nothing, but your the most critical obstacle.

So, if this is the most critical obstacle. Now, based on that I will have to make the planning how to make the planning now what we do is. So, this is the initial position this is the final position and this is the most critical obstacle. So, what we do is we try to find out the distance between the robot and your the most critical obstacle. So, this distance or up to these distance we consider as one of the inputs for the motion planner. And another input will be the angular information that is the angle between the goal, the present position of the robot and this particular obstacle. So, we try to consider. So, these particular angle as one of the inputs. So, we have identified. In fact, two inputs for this particular process. One is nothing, but the distance. So, the distance between the robot and the most critical obstacle and another is nothing, but the included angle.

So, the angle between the goal the present position of the robot and these particular the obstacle. And what should be the output. The output is actually the angle through which the robot should move to avoid collision with these most critical obstacle.

Now, supposing that. So, this is the angle of these particular deviation like if the robot wants to avoid collision with these particular the most critical obstacle supposing that the

robot should deviate by these particular the angle. So, the output is nothing, but is your the deviation angle and there should be another output. That is your the speed of these particular robot; that means, your the speed or the velocity with which these particular robot is moving to a while avoiding these particular the collision.

Now, the speed is decided by the acceleration. So, we try to find out the acceleration of these particular robot as one of the outputs. So, this is nothing, but the motion planner and there are two inputs like one is your the distance, another is the angle and there are two outputs. One is the deviation, another is nothing, but the acceleration. Now, let us see how to model. So, this particular problem with the help of say the fuzzy logic system or how to how to model with the help of some neuro-fuzzy system.

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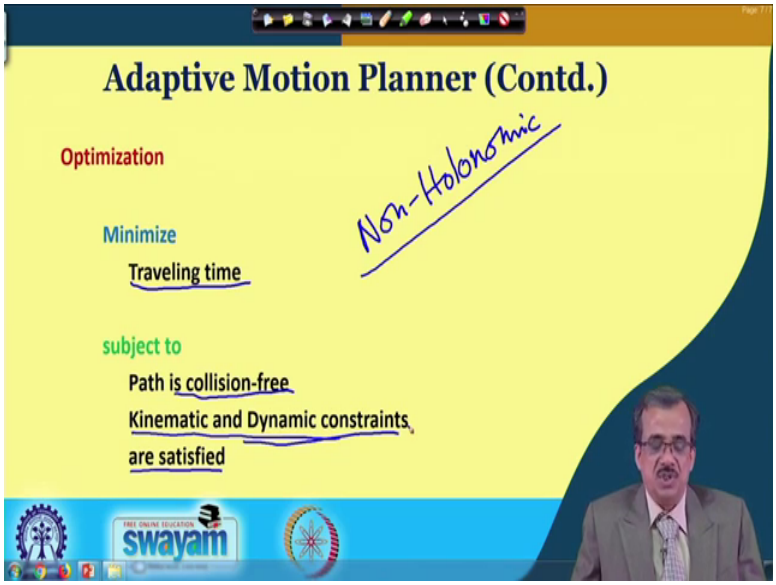

Now, before I go for that. So, this can be treated this particular problem whatever I stated. So, this can be treated as an minimization problem or the optimization problem where the aim is to minimize the travelling time. So, our aim is to minimize the travelling time subject to the condition that the path is collision free. There should not be any collision between the robot and the obstacle and the kinematic and dynamic constraints are to be satisfied. Now, here as I told that this is actually a car like robot and if it is a car like robot. So, we will have to consider the non-holonomic constraint. So, I am not going to concentrate on this non-holonomic constraint and all such things related to robotics.

So, actually this course does not permit to discuss all such things. So, I am not going to discuss, but let me tell you that whenever you are going to make some planning for this particular movement, the kinematic constraint like non-holonomic constraint then the dynamic constraints like your that generated talk or the force and all such things those are to be well those are those should like within your the pre specified range.

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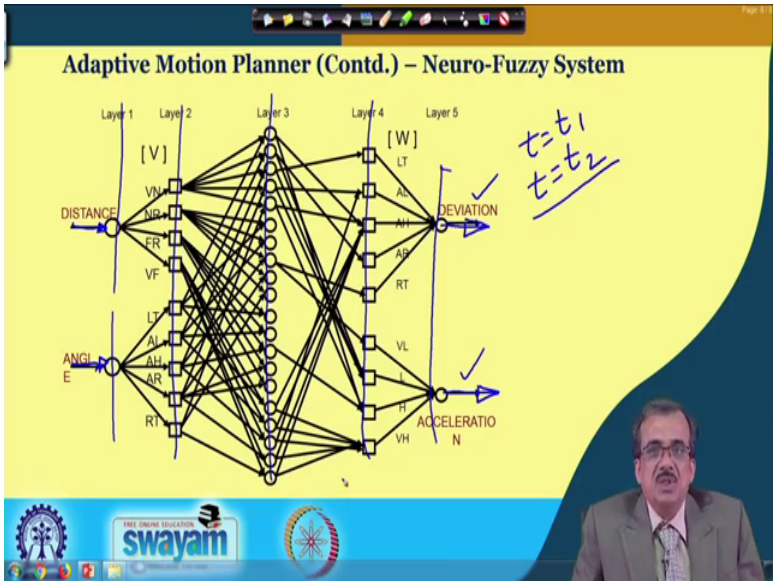

Now, after maintaining all such your the conditions the constraints. So, I will have to make some planning for the movement of these particular the robot. Now, this schematic view like it shows how to tackle these particular problem using the structure of your the neuro-fuzzy system, the Mamdani approach. Now this I have already discussed in details while discussing the neuro-fuzzy system the Mamdani approach. Now, you see the problem the physical problem which I discussed that can be tackled very efficiently. So, using these particular the structure of neuro-fuzzy for example, say as we have already discussed it consist of five layers. So, we have got layer 1 is the input layer, layer 2 is the fuzzyfication layer, layer 3 is the end operation layer, layer 4 is the inference engine layer and layer 5 is nothing, but the output.

Now, here I am passing two inputs. One is the distance and another is your angle and ultimately I will be getting two outputs. One is the angle of deviation and another is nothing, but is your acceleration. Now, its working principle I have already discussed and we have solved some numerical examples also. So, I am not going for that now the

thing which I am going to discuss. So, these particular neuro-fuzzy system. So, we will have to design and develop as a motion planner adaptive motion planner.

Now, depending on the inputs like distance and angle. So, it will try to find out what should be the angle of deviation and what should be the acceleration of the robot. Now, using the information of acceleration as I told we can find out like what should be the speed or the velocity. So, this is actually how to use one fuzzy reasoning tool based on Mamdani approach using the structure of a neural network. Now, these particular neuro-fuzzy system we can train with the help of some nature inspired optimization tool like genetic algorithm.

Now, if you use genetic algorithm. So, through a large number of iteration. So, GA will try to evolve these particular the neuro-fuzzy system. Now, this neuro-fuzzy system, the evolve neuro-fuzzy system can be implemented online at the different steps of these particular the motion planning problem. Now, as I told that these motion planning problem will be solved step wise. So, at time t equal to t 1, I will try to find out what should be the step direction. And next once again at time t equals t 2 once again. So, I will have to replan with the help of these trained neuro-fuzzy system.

So, it is possible and very easily actually we can tackle these type of problem and we carried out some real experiments also. I will give you how to carry out these experiment and we will see that that we can develop. So, these type of neuro-fuzzy system as the adaptive motion planner.

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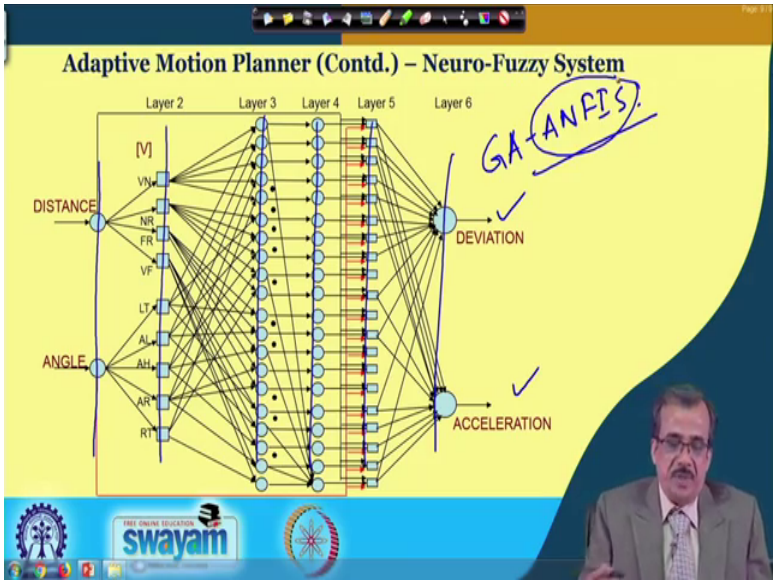

the next comes your the same problem how to tackle with the help of ANFIS. Now, once again the ANFIS has got like layer 1, layer 2, layer 3, layer 4, layer 5 and layer 6. And this working principle of ANFIS we have already discuss in details and we have solved some numerical example. So, I am not going to discuss the working principle of these particular ANFIS. The thing which I am going to discuss is if I pass a set up two inputs like distance and angle. So, there is a possibility will be getting the deviation and acceleration for these particular robot. So, that it can avoid collision with these particular the moving obstacles.

Now, here as I told once again I can use a genetic algorithm like I can develop these GA ANFIS. And GA will try to evolve these particular the neuro-fuzzy system based on Takagi and Sugenos approach that is nothing, but ANFIS and. So, this particular evolved ANFIS will be able to tackle the your the problem the motion planning problem in a very adaptive way in a very efficient way.

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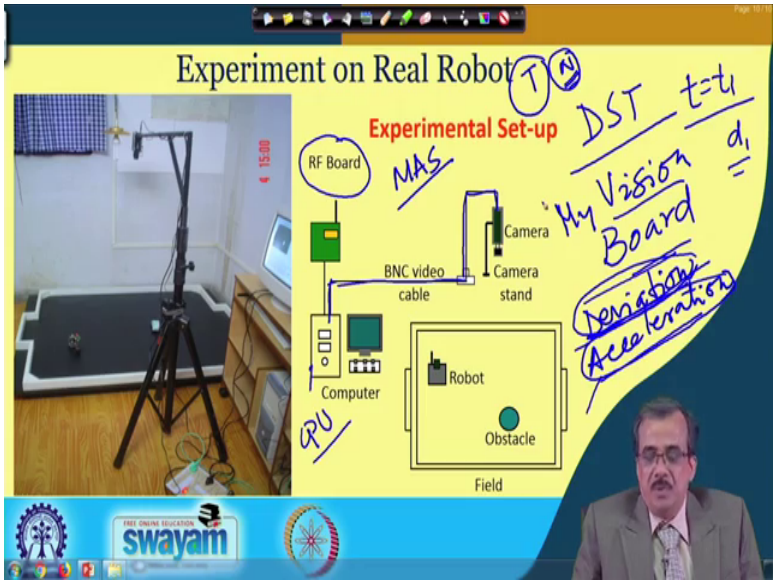

So, this shows like how to use the fuzzy reasoning tool using the structure of a neural network and which works based on the Takagi and Sugenos approach.

Now, once if develop these particular algorithms. So, we try to implement on the real experiment. Now, let us see how did we carry out the real experiment just to implement your these type of adaptive motion planner. Now, before I proceed let me tell you that we got one project Department of Science and Technology, Government of India. So, this DST project actually we got and with the help of DST project we implemented this real experiment. So, DST, Government of India funded these particular the project.

Now, let us see how to how to tackle. So, this particular the problem. Now, here you see. So, I have got a field and inside this particular field. So, I have got one robot and I have got one moving obstacle. Now, let us see how can these particular robot avoid collision with these particular the moving obstacles. Now, how to tackle these particular the problem. Now, to tackle this particular problem the first thing we will have to do is we will have to capture information of the environment. How to capture this information of the environment. To capture the information of the environment we will have to use some camera.

Now, here we have used one overhead camera. Now, similarly there could be onboard camera also now with the help of these overhead camera. So, what you can do is we can take a snap at a regular interval of these particular the environment. So, you will be getting some picture. Now, that particular picture actually collected with the help of this

CCD camera will pass through the BNC video cable and this will enter actually the CPU that is the computer. So, here we have got the CPU and on the CPU we have got one my vision board that is the hardware to carry out your the image analysis. So, inside this particular CPU we have we had my vision board as I told that this is nothing, but the hardware just to implement your the computer vision or the robot vision.

Now, with the help of this my vision board. So, what we can do is we could find out we could carry out the image analysis. And through this image analysis we can find out the information of these particular the environment; that means, we can find out the position of these particular robot. We can also find out the position of these particular your the obstacle. And once we have got the position of this robot and this obstacle now, we are in a position to find out what should be the distance input that is the distance between the robot and the obstacle and it has got a goal. So, with respect to goal what is the angle input that also we can find out. And once we have got that now, we are going to use like neuro-fuzzy based motion planner just to find out what should be your angle of deviation and how much should be the acceleration of these particular the robot.

So, we have got this particular information that is your deviation of these robot and another is nothing, but the acceleration. Now, this particular information we find out corresponding to a particular the time step or a distance step; that means, I am just going to do this planning at time t equals t 1 for a small distance that is nothing. But d 1 and once again I will have to re-plan at time t equals to t 2 corresponding to another distance step say d 2 and so on.

Now, supposing that. So, we have got the deviation and acceleration. Now, we will have to achieve this particular deviation and acceleration. Now, how to achieve this particular acceleration and deviation as I have already mentioned that we carried out this particular experiment on a two wheeled one casta robot. And that is nothing, but actually two wheeled differential drive robot and.

So, these to operate these particular robot, we had two DC motors and who is going to generate the movement of the wheel. It is actually the DC motors and for these DC motors there should be a controller.

Now, we use PID controller just to find out like just to control these particular the motor. Now, what do you need is we will have to calculate how much should be the torque

generated by the motor mounted at the two wheels. And how much should be the rpm so that we can reach. So, this particular angle of deviation and a particular value of acceleration of this particular the robot that can be determined mathematically or analytically. And once you have got this particular information that what should be the torque and what should be these particular rpm of the two motors mounted at the your the two wheels. Now, we will have to implement that, how to implement. So, these particular information that what should be the rpm of the right wheel and what should be the rpm of these particular the left wheel.

So, this particular information the calculated information we will have to pass to this particular controller of the motor. And how to pass, we took the help of some radio frequency module that is the RF module and this is wireless communication and through this RF module. So, this information is going to the controller and the controller is going to control the movement of the robot. And ultimately we will be getting the accurate movement of these particular robot; that means, we will be able to develop. So, the angle of deviation and we will be able to follow a particular the prescribed value for these particular acceleration or speed of the robot.

Now, this is the way actually we implemented and we carried out the real experiment. Now, this is a very simple experiment. Now, to make it more complex. So, what we will have to do is we will have to consider more number of your the moving obstacles or we can consider the more number of your the mobile robots. Now, if I consider more number of mobile robots like multiple robots. This will become once again the multi agent system of robotics which I introduced little bit. So, ultimately the problem related to the multi agent system of robotics has to be solved and that is not an easy problem. As I told and one thing here I want to mention that all such activities are to be done within a fraction of second otherwise there is a chance of collision between.

So, this particular robot and your the moving obstacle; that means, all such things all such steps we will have to implement within a fraction of second then only we will be able to carry out. So, this particular the experiment.

Now, as I told that this particular the training of the motion planner. So, that is carried out actually offline because if you take the help of some optimizer. So, it will be computationally very expensive. So, online trading could be difficult. So, within a

fraction of second we may not get that particular the information and that is why. So, this particular motion planner the adaptive motion planner the training is provided offline.

Now, if we can implement the online training that will be much more interesting, interesting in the sense like supposing that. So, this is the field and we have got a large number of the robots the planning robots and we have got a few obstacles also all are moving. Now, initially actually there could be a few collisions. Now, from these collisions and the experience. So, it will gain some information and if you want to if you can take the feedback and if you can implement. So, that type of training scheme. So, there is a possibility that we can implement the principle of online training.

So, by online training we means the robot will be working and while working actually it will try to learn from the environment from its success and failure.

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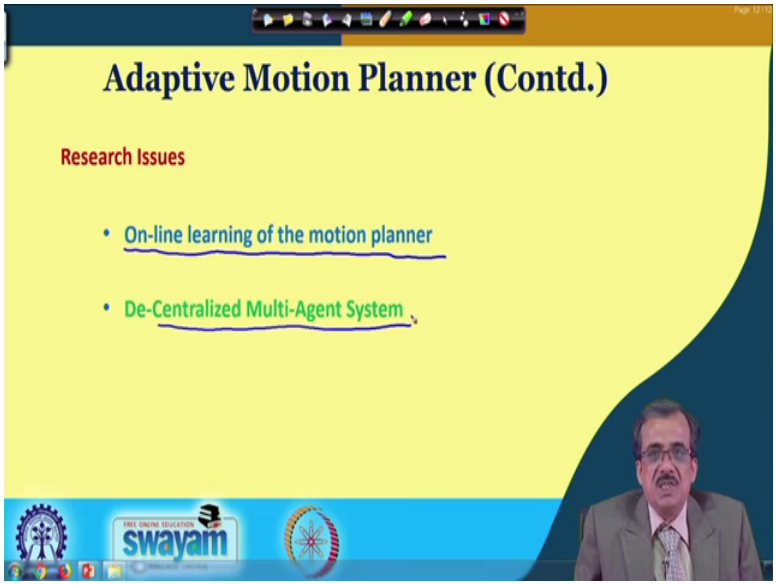

And that is actually what do you mean by the online your the learning of the motion planner. Now, if we can implement. So, these particular online learning of the motion

planner that will be much more interesting because for this offline training there could be a few scenarios which could be bit difficult to foresee beforehand and there actually this online training is going to help a lot.

So, the same principles of fuzzy logic and neural networks can be utilized just to implement the online learning of these particular the motion planner. And next is your decentralized multi agent system of robotics. These I have already discuss. Now, let me once again discuss little bit. Now, this decentralized multi agent system of robotics is bit difficult to implement. Now, supposing that I have got two teams of soccer plane and each team say consist of say, say for simplicity only six players.

Now, each of the six players is having its own goal and that is actually are dependent on the main goal of the team. What is the main goal of the team, to win that particular match or to score the more number of goals. Now, to win this particular match or to score more number of goals. So, they will have to follow some strategy and these robots the six robots they will have to work accordingly.

There will be competition with the opponents and there will be cooperation among the team mates and through these competition and operation. So, these multi agent systems that is the intelligent robots are going to reach that particular goal that is to reach that your to win that particular the game. Now this particular principle of cooperation and principles of competition can be implemented very efficiently using the principle of your fuzzy logic and neural networks.

Thank you.