Lecture 14: Experiment 05: Path and Gait Planning of 25 dof NAO Humanoid Robot

I welcome you all to experiment 5 of this NPTEL course on Experimental Robotics. The title of this experiment is Path and Gait Planning of 25 degrees of freedom humanoid robot. Now, the path and gait planning for a humanoid robot are to be done one after another simultaneously. Now, here it involves path planning as well as gate planning. Now, let us try to understand the meaning for the path planning and the purpose of the gait planning.

Now, this experiment we are going to conduct with the help of this humanoid robot, that is, this humanoid robot is having 25 degrees of freedom or mobility levels. Now, supposing that this particular humanoid robot is going to negotiate one staircase. Now, while negotiating the staircase, the robot will have to make a plan, where to place his feet or say the moving foot and accordingly, the sequence of the leg movements is to be decided so that it can negotiate the staircase by consuming minimum energy and by maintaining the maximum dynamic balance margin. That is why, the path planning and gait planning are to be considered for a humanoid robot for its effective navigation.

Now, in this particular experiment, I am just going to discuss what are the things to be done and this slide shows the concept, which I am going to discuss in this particular experiment. So, to start with, I will give a brief introduction to the concept of multi-legged robots and that too, I will concentrate on the two-legged robot or the humanoid robot. So, we are going to use a particular humanoid robot, that is, the now robot to carry out this particular experiment. So, I am just going to describe the different components used in this particular setup of humanoid robot. Next, I will be concentrating on the specification details of this setup on humanoid robot.

The aims and objectives of this particular experiment will be discussed in detail and to carry out the real experiment, we will have to follow a few steps. Those steps we are going to discuss before we carry out a few predetermined tasks. So, the planning of the real experiment and the task to be considered during the real experiment, we are going to discuss in details. Now, through this particular experiment, a few inferences will be drawn. Those things I am just going to discuss one after another and to conduct this particular experiment, some precautions are to be taken.

So, those precautions I am going to discuss point-wise. Some application areas of this type of humanoid robot, we are going to discuss and a few references will be given at the end, so that the participant can collect more detailed information regarding this humanoid robot. So, let us start with the introduction. Now, all of us, we know that we have got different types of multi-legged robots and multi-legged robots are actually preferred, whenever we have got a very rough terrain and to negotiate the rough terrain, there is no way out, but we will have to go for the multi-legged robots. Now, if you see the literature, the multi-legged robots are available in the form of insects or in the form of animal or in the form of the human beings.

Now, this eight-legged robot or the six-legged robot are a look-wise similar to the insects. Four-legged robot is nothing, but look-wise similar to the animal and two-legged robots resembles the human being. Now, let us try to find out that why do you get the various types of multi-legged robots. Now, to answer that, we will have to concentrate on a particular aspect while considering the multi-legged robot and that particular aspect is nothing, but the balance of the robot. So, how to maintain the balance of a eight-legged or a six-legged robot, how to maintain the balance of a four-legged robot and how to maintain the balance for the two-legged robot.

Now, here these robots can be used for tackling the rough terrains like staircases, ditches, inclined surfaces and others. And as I told while negotiating the staircase, these robots will have to maintain their dynamic balance and at the same time, it should be able to perform the task by consuming the minimum energy. So, that the power requirement or the power rating of the different motors put at the different joints should be as minimum as possible. Now, supposing that we have got the necessary power, then the main important thing is how to maintain the balance. Now, if I concentrate on the eight-legged robot or the six-legged robot or the four-legged robot, these robots could be either kinematically stable or dynamically stable and maintaining the balance or the stability of these eight-legged, six-legged, four-legged robots will be easier compared to that of a two-legged robot or the humanoid robot because the two-legged robot or the humanoid robot may not be kinematically stable and we will have to find out the dynamic stability of a two-legged or a humanoid robot.

So, even if a humanoid robot or a two-legged robot standing at a particular location, the robot has to be dynamically balanced, it may not be kinematically balanced and that is why the balancing of a two-legged robot or a humanoid robot is much more difficult compared to that of other multi-legged robots like four-legged, six-legged or eight-legged. Now, in today's experiment, we are going to see how to maintain that particular dynamic balance of a humanoid robot. Now, as we mentioned that humanoid robot, we try to resemble the appearance, behaviour and activity of a human being and it is very difficult to copy the activities of a human being in the artificial way and develop it in the form of a humanoid robot. And, that is why, designing and developing the humanoid robot is the most difficult task among all the robots. So, maintaining the balance of a humanoid robot is a very difficult task, which I am going to discuss mathematically and then, we are going to show you through experiments how to maintain that dynamic balance for a humanoid robot.

Now, if we concentrate on the working cycle, the working cycle of a humanoid robot consists of two single support phases and two double support phases. Now, during the single support phase, out of the two legs or out of the two feet, one will be placed on the ground and the other one will be in air. So, there will be only one single, there will be only one support foot and that is why this is known as the single support phase of a robot. And during the double support phase, both the feet will be placed on the ground and that is called the double support phase. Now, if we consider the working cycle of a humanoid robot, say we start with a double support phase, a particular working cycle.

So, the first will be the DSP, that is the double support phase and it will be followed by one single support phase, where only one foot will be placed on the ground and the other foot will be in air. The moment that particular foot, which was in air, it will be placed. So, once again I will be getting the DSP, that is the double support phase. So, once you have got this particular the double support phase, what happens? Once again, the rear foot that will be brought to the direction of movement and once again there will be a single support phase. So, two single support phase and two double support phase is going to constitute one working cycle for a humanoid robot.

And of course, between one double support phase and the single support phase, there will be one transition phase. Similarly, one single support phase and one double support phase, there will be another transition phase and there will be a transition phase between the last DSP and the last SSP of one working cycle. So, there will be three such transition phase for a small duration, very small duration. Now, to maintain the dynamic balance during one working cycle of a humanoid robot, dynamic balance has to be maintained during the double support phase, during the single support phase and it has to be maintained between the transition phase also. Now, those things I am just going to discuss in details mathematically, how to ensure the dynamic balance margin during the single support phase and double support phase.

So, the humanoid robot should maintain its dynamic balance both in single support phase and double support phase. So, that I am going to discuss mathematically after sometime. Now, this humanoid robot, we are copying everything from a human being and we human-beings take any decision and that particular decision is a combination of intelligence and emotion. So, if you want to copy in an artificial way a human-being in the form of a robot. So, this robot has to be intelligent, at the same time, it has to be emotional and robot should get that particular authority to take the decision of its own, so that we can make the robot autonomous.

So, the humanoid robot should be made intelligent, autonomous and emotional. So, how to make it? So, we will be discussing a little bit and through the real experiments also, we will try to show you that how to make the robot intelligent and autonomous. Now, here I am just going to discuss the fundamental of walking and to explain it, what I am going to do is, I am just going to take the example of a very simple the humanoid robot and that particular simple humanoid robot is known as a biped robot. So, here you can see, this particular biped robot for simplicity, let me consider. So, I have got one joint here, I have got another joint here, another joint here.

So, in one leg, we have got three joints, three rotary joints. Similarly, on the other leg, we have got three other rotary joints. So, 3 plus 3, we have got six joints on two legs and here also, we have got another joint. So, I have got seven joints here and each joint is having one degree of freedom and consequently, this particular the biped robot is having the seven degrees of freedom. So, with the help of this particular the robot, I am just going to show you.

So, how to maintain the dynamic balance? So, mathematically, I am just going to show you. Now, here as I told, you can see that only one foot that is the left foot is on the ground and right foot is in air. So, this is nothing but a single support phase. Similarly, you can see that here both left and right are on the ground and this is nothing but a double support phase. Now, in between this single and double, we can see, we have got a transition phase sort of thing.

Similarly, after this DSP, there will be a single support phase and this could be the transition phase. So, I can say roughly this shows half of one working cycle, almost half not exactly half, almost half of one working cycle and in one working cycle, as I mentioned, there will be two single support phases and there will be two double support phases. So, how to maintain the dynamic balance during the single support phase and the double support phase? So, that I am going to discuss, ok? So, with the help of this particular schematic view, I am just going to discuss the concept of the dynamic balance during the single support phase and the double support phase. Now, let me try to concentrate on this particular single support phase and how to maintain the balance. Now, here you can see, there is one foot, which is in air and another foot is in ground and let me consider, so this particular the ground foot.

So, let me draw it like this. So, let me prepare one rough sketch for this particular the ground foot, that is your the left foot. Now, the moment I am considering, this particular foot is in on ground. So, I have got one joint here, rotary joint say revolute joint, I have got another joint here, another revolute, I have got another joint here, another revolute. So, for simplicity, let me consider this and let me also consider that here also I have got a joint, I have got a joint, I have got a joint, I have got another joint.

Now, in between the two joints, I have got a link and let me assume that this particular link is having some mass and for the purpose of analysis, let me consider that mass is concentrated in this particular link, that is the lumped mass m_1. Similarly, the lumped mass for the second link might be here and let me consider this is m_2 . Similarly, for each others, we have got the lumped masses, we have got the lumped masses here, lumped masses here, we can also consider the lumped mass, we can also consider the lumped mass. So, we have got all the lumped masses. Now, if we consider that this particular joint is moving, what will happen? The lumped masses are going to have some displacement and all of us, we know it has got a mass and it must have got some acceleration and mass into acceleration is going to give me, how much is the force acting.

So, I can find out how much is the force acting, that is your mass into acceleration. Now, to conclude, let me tell you that each of these particular lumped mass is subjected to some amount of force. So, here I have got say F_1, I have got F_2, similarly, as if at each of the lumped masses some force is acting. Now, if there is a force acting, this force is going to create some moment. So, force is going to create some moment, all of us we know that force multiplied by the lever arm or that particular arm distance is nothing but the moment.

So, force is going to create moment and there could be some concentrated moments also. So, this particular foot, which I have drawn it here, so this is the foot area and here, a large number of moments, moments due to force, moments some concentrated moments are acting. So, what we will do is, we will try to find out one point about which the sum of all the moments, the moments due to force, the concentrated moments becomes equal to 0. Now, if this is the ground foot, so might be the ankle joint could be here, let me assume the ankle joint is here and say this is the direction of movement. So, we try to find out a point, a hypothetical point about which the sum of all the moments becomes equal to 0.

Now, supposing that that particular point about which the sum of all the moments becomes equal to 0, so it is here and that particular point is known as the ZMP, that is your Zero Moment Point. So, this is known as the Zero Moment Point, ZMP. Now, here this point is what? This is actually the connecting point between the foot and the first link of the leg and this is the ZMP and this is the direction of movement. So, using this particular information of this ZMP, that is a point, a hypothetical point about which the sum of all the moments becomes equal to 0. So, we can find out how much is the stability margin.

Now, if this particular point is lying within this particular shape region, then only we declare that this single support phase is dynamically stable. Now, this point if it goes outside here or here, then the balance will be lost and this particular robot is going to fall, lose the balance. So, to repeat, to maintain the balance, to maintain the dynamic balance, so this particular ZMP should lie within this particular support region. So, this is nothing but the support region for the ground fall. And, this particular ZMP has got another physical meaning.

Now, whenever a humanoid robot is standing at a particular location, there must be some ground reaction force acting. So, this is the point through which the ground reaction force is going to act vertically upward or at some angle. So, this is the concept of the zero-moment point or ZMP with the help of which we can explain the balance, the dynamic balance margin of a particular robot. Now, if this is the direction of movement, say this is direction x and this is the edge up to which we can maintain the dynamic balance and the ZMP is here. So, if the ZMP comes very near to the edge, then we will be in difficult situation and the moment it comes out of that particular edge or the support region, the balance will be actually lost.

If it is so, this particular difference is going to give us the dynamic balance margin in the x direction, if this is the direction of x. So, this is known as the dynamic balance margin DBM, dynamic balance margin along the x direction. Similarly, if this is the y direction, we can also find out what could be the dynamic balance margin along the y direction. So, this is in short like how to maintain the dynamic balance during the single support phase. Now, I am just going to concentrate on how to maintain the dynamic balance during the double support phase, where both the left foot as well as the right foot are on the ground.

Now, if I just draw it roughly, so this is one foot in the double support phase and this is another foot and say this is the direction of movement. So, if this is the direction of movement, let me consider this is the left leg and this is the right leg and this is the x direction. So, how to determine this particular analysis or how to carry out the analysis to determine the dynamic balance margin during the DSP, that is the double support phase that I am going to discuss. Now, remember double support phase could be little bit a comfortable situation for a humanoid robot compared to a single support phase. On the other hand, maintaining the balance is easy, but carrying out the analysis mathematically is much more difficult.

And, in fact, during the double support phase, carrying out mathematical analysis to find out the dynamic balance margin is difficult. And, that is why what we do is during the double support phase is assumed is a combination of two single support phases and exactly the same way, we try to carry out the analysis using the concept of your ZMP. So, what we do is during the double support phase, depending on the relative position of the two feet left foot and the right foot, we try to find out what is the distribution or redistribution of the load. For example, I am negotiating staircase. So, this load distribution depends on a few things, it depends on the geometry of each of the stairs, it depends on the slope of that particular staircase, it depends on the length of the different limbs of that particular the humanoid robot and so on.

So, considering everything, I can find out how much is the load coming mathematically on the left foot and how much is the load coming on the right foot. So, very easily using simple mathematics, we can find out the distribution of the total load on the left foot and the right foot. And, once you have got this particular distribution of the load on the right foot and the left foot, what we do is we try to carry out the analysis for your dynamic stability margin. Using ZMP separately and what we do is for this left foot, so we try to find out actually we try to find out one ZMP direction and this is nothing, but ZMP for the right foot and we also try to find out the ZMP for the left foot and that is nothing, but the ZMP for the left foot. Now, what we do is, we try to find out we try to extend this particular ZMP direction and that particular ZMP direction to find out one point of intersection hypothetically.

And, once you have got this particular the point of intersection, we take the projection. So, what we do is, if this is the right foot, this is the left foot, we try to find out how much is the safe support region. So, this particular region is the safe support region for the double support phase and what we do is, we try to take the projection of this particular intersection point on the ground and supposing that it is here. And, if it is here, then this particular point is considered as ZMP for the system and the system is in double support phase. And, we try to find out the distance between this ZMP system and this edge and this is going to give us actually the dynamic balance margin or the stability margin along the x direction.

So, we can also find out what could be the dynamic balance margin along the y direction also. So, that is also possible. So, this is the way mathematically we try to find out whether the robot during its single support phase as well as in double support phase, whether it is in the balanced one or it is able to maintain its stability, the dynamic stability. Now, once you have got this particular thing, now you can concentrate on the description of the setup with the help of which we are going to carry out this particular experiment. So, this is the 25 mobility levels or 25 degrees of freedom the biped robot that is the now robot, which we are going to use for this particular the experiment.

Now, here I am just going to show you the different components of this particular the robot. You can see that we have got a foot here and the knee joint you can have a look. So, this is the knee joint and we have got one ankle joint here also. So, this is actually shows the ankle joint, knee joint and there will be a hip joint here also. So, we have got the ankle joint, knee joint, hip joint at each of the two legs.

Then, we have got a few other joints like we have got on the hand the wrist joint, then we have got the elbow joint, we have got the shoulder joint, we have got the head joint here. So, these are the joints, which we have here and there are a few sensors mounted on the different parts of this particular the humanoid robot. There are a few microphones, speakers, sensors, cameras, those things I am just going to show you. You can see that we have got one tactile sensor, then we have got speaker here, we have got microphones front and rear. So, there are some microphones front on the front and rear, we have got the camera, the camera is mounted on the forehead, another camera is mounted on the mouth.

Then, we have got a few other lateral microphones also. Then, we have got the sonar sensor, you can have a look. So, there are some sonar sensors here. So, these are the sonar sensors we have. Then, there is a chest button with the help of which we can switch it off and on.

Then, there will be a battery here. So, the battery for this particular the robot is put here, you can have a look. Then, comes your a few tactile sensor, we have the touch sensor, we have got one tactile here. So, we have got another set of tactile sensor here. So, these are the components, the main components for this particular the robot. And, another thing we missed, we have got some infrared sensor emitter and sensor here.

So, these are the different components of this particular 25 degrees of freedom, now even at robot with the help of which we are going to conduct the experiment. Now, here I just want to tell you one thing, one very fundamental. Although, we speak that this particular robot has got 25 degrees of freedom, truly speaking this statement may not be correct 100 percent because by definition degrees of freedom cannot be more than 6. So, truly speaking this 25 degrees of freedom is nothing, but 25 mobility levels. So, better to say here the mobility levels of mobility, so 25 levels of mobility it has.

So, with the help of this particular the robot, we will see how to carry out the experiment, how to control it with the help of some CPU or the computer, how to use some their software to control this particular the robot, so that this robot can perform different types of tasks. Now, to continue with the description of the setup, so I am just going to tell you as I have already mentioned that it has got 25 degrees of freedom roughly speaking because is the mobility levels. So, out of these 25, we have got 11 degrees of freedom in the lower part. So, in the lower part, in fact, we have got the hip joint, then comes your the knee joint and the ankles. So, we have got the ankle joint, the knee joint and we have got the common hip common to both the legs.

So, each leg we have got 5 degrees of freedom, so 5 plus 5, 10 and 1 at the hip joint. So, we can get 11 degrees of freedom for the mobility levels and the upper part of this particular humanoid robot has got 14 degrees of freedom, which includes the mobility levels at the shoulders, elbows, wrists, then hands, necks considering all the things together, we have got 14. So, 14 plus 11 will become 25. Now, if you see the construction height of this particular robot is 58 centimeter that means slightly less than 2 feet and weight of this particular robot is 5.48 kg more or less equal to 5.5, 5 and half kg. And, we use one software that is called the the choreography software sort of thing and with the help of this choreography software, in fact, we are going to control the movement of this particular the physical robot. So, how to control it with the help of this choreography software that we are going to discuss in details after some time. Now, here I am just going to tell you, so how to connect this particular the software and how to control the physical robot with the help of this choreography software. Now, here you can see this is the display, which will be getting on the computer all the PC connected and this particular computer will be used to control the movement of the robot with the help of this choreography software. Now, here on the screen, you can see that there is one virtual robot on the computer screen.

So, this is the virtual robot and here you can see that a few symbols, this particular green symbol indicates we are going to start, red indicates we are going to end the program and on that your left hand side or here you can find out there are a few subroutines sort of thing. So, depending on the task to perform a particular task might be there are a few sub-tasks and for each of the sub-task, we will have to use some library function, which are included here. And, we will have to select those library function one after another in a particular sequence and we will have to prepare this particular sequence of operation. So, each of these particular modules is nothing but a sub-task and all such sub-tasks are to be conducted in a particular sequence to execute one main task with the help of this choreography software. So, all such links are made and then what we do is, we can see this particular virtual robot and this information, we will have to pass it to the real robot on which we are going to conduct the experiment and it has to be connected.

So, this information from the choreography, it has to be connected with the help of a LAN to the physical robot and once it is connected, now we can press this particular button to compile and run and execute that particular program and you will see that we will be able to control the physical robot depending on our requirement to carry out a particular the task. So, this is the way we can carry out the real experiment with the help of this particular the humanoid robot, that is the now humanoid robot. Now, with this information, I am just going to concentrate on the information to be provided while writing the specification for this particular the robot or the setup. So, as I told that this particular humanoid robot model has got 25 mobility levels or degrees of freedom and it is your the NAO humanoid robot. Now, this particular robot has got two legs and each leg is having five degrees of freedom, which I have already discussed and as there are 11 degrees of freedom on two legs and the hip connecting hip joint, so there must be 11 motors.

So, each of the motors is going to control the movement of one of the joints. So, each motor is responsible to generate one degrees of freedom and these motors the movements are to be generated as accurately as possible. Consequently, these motors are to be servo motors and there must be closed loop control system. The robot has got two arms and each of the arms is having six degrees of freedom. So, two legs, two arms and two legs will be connected at the hip joint and it has got a neck with two degrees of freedom.

So, this particular 11 plus 2 arms 6 multiplied by 2, so we have got 12 here and 11 here, so we will be getting 23 plus 2 on the neck, so we will be getting these 25 degrees of freedom. So, the robot has got the rechargeable lithium-ion battery. So, we use rechargeable lithium-ion battery, so this can be charged and once it is fully charged, we can use it for 60 minutes in active use and 90 minutes in normal use. And, this robot this setup has got two cameras, one camera is put on the forehead as I told and another is on the mouth. So, with the help of these particular cameras, we can take the picture, we can do image analysis and by doing image analysis, we can find out the information, the related information of the surrounding, we can find out.

We have got the processor like for this particular robot Intel Atom E3845 processor with 2 GB RAM and 8 GB of flash memory, we have. The operating system, so this particular robot can be used in different operating systems like we can use it in Windows, then Mac operating system or Linux operating system of Unix, you can use, we can make the program, we can compile it and we can control it this part in different operating system. Now, regarding the programming languages, different types of programming languages can be used to control this particular the robot. For example, we can use C++, we can use Python script, we can also use Java. So, the programming can be used can be written either in C++ or Python or JavaScript.

So, this is these are the way, we can write down the program just to give information regarding the task to be performed. Now, regarding the connectivity, besides that LAN connection, WAD correction, it has got some Wi-Fi connection and Ethernet through Ethernet Wi-Fi. So, this particular robot can be connected. So, wirelessly also we can control with the help of this Ethernet and Wi-Fi, because if you want to control this particular robot, some control commands will have to send, users would be able to send it and the robot should also receive it a few commands wirelessly. So, all such things can be made possible in this particular setup on humanoid robot.

Now, with this description of the setup which we have and the specification, now I am just going to tell you the aims and objectives of the experiments which we are going to conduct. So, what we are going to do is, we are going to study the various components of a humanoid robot, how we can generate motion at the different joints of the humanoid robot, how to generate the motion, how to get the combined motion considering all the joints and these particular the links and we can study the construction details of this particular the humanoid robot. And, once we have got the construction details, how does it work and all such things, we can make the program to perform a particular task and according to that particular program, we can try to control that particular the robot, so that it can perform the pre-assigned task. And, we are just going to consider the working of this particular robot, different types of working like the forward movement, backward movement, it should be able to take turns and all such things to perform some pre-specified task. So, based on this particular objectives, before just going to discuss the task to be performed, a few steps are to be followed to carry out the experiment and those steps I am just going to tell you in short.

Now, step 1, we download and install that choreograph software from the official website of Aldebaran Robotics because now this Aldebaran Robotics is actually the manufacturer and supplier of this particular robot. And, from their website, we can find out this particular choreograph software, we can download on the PC or the computer through, which we are going to control. So, we attach the LAN-wire to the real humanoid robot and this robot is turned on by pressing the chest button, which are shown for a longer duration say 2 to 3 seconds and then only, we can put the power on for this humanoid robot. And, once that power has been put on, we can use the IP address of the robot and then, what we can do is, we can get this IP address by pressing the chest button only once and this IP address will be required to connect the choreograph software. So, what we do is, with the help of this IP address and the LAN connection, we can connect the physical now robot with the choreograph software and the program will be written using the subroutine or the library function of choreograph software and a set of program, set of activities will be connected, so that it can perform a particular task, the pre-assigned task.

And, once it is decided, then as we told we connect the virtual robot through which the choreograph software will be working. The virtual robot is connected to the physical robot through LAN and IP address and we can control the physical robot depending on the requirements. Now, during the real experiment, these are the tasks which we are going to conduct. The task 1 is identification and movement of different joints of the robot. The robot has got so many joints, so many rotary joints and we are going to control the movement of the different joints might be you can move one at a time and show that particular the movement.

Then, task 2 is the forward and backward movement of the robot and the robot should be able to take turn also. So, that particular experiment we are going to do and the third task with the help of these particular the different joints, the robot will be able to show some dancing movement also. And, we will see that as I told that maintaining the balance is the main problem our humanoid robot will be facing. And, while dancing, you will see that the lower part that will not be changed much and dancing activity will be performed with the help of upper joints mainly with the help of upper joints. Because, if you move the lower part joints, there could be a some stability problem also or balance problem also.

Then, task 4, we will try to control the joints of the now robot at different time frames. For example, different time scale, different time step, so we can control the different joints. So, if you increase the time scale or the time step, we can decrease the time state accordingly, we can increase the speed or decrease the speed. So, that type of movement, you can have a look at different time step. Then, task 5, we will be able to assign the joints position that is the angular displacement and the torque values and these things will be monitored with the help of the software.

So, that thing will be the task 5, because to perform different types of task, the robot's joints are to be controlled and the angular displacement velocity and acceleration, we should be able to generate at different rate and at the same time, the torque has to be generated, the different or the varying values of the torque has to be generated for conducting the different types of activities. Thank you.