Lecture 08: Experiment 03: Path and Gait Planning of Six-legged Robot

I welcome you to experiment 3, that is, Path and Gait Planning of Six-legged Robot for our NPTEL course on Experimental Robotics. Now, here, we are going to do experiment using a six-legged robot. Now, this particular six-legged robot is one of the most popular forms of mobile robot. Now, if you see the literature mobile robots are available in various forms. For example, we have got the wheeled robots, we have got the multi-legged robots, we also have the tracked vehicles. Now, if the terrain is smooth, we generally go for the wheeled robot.

On the other hand, if the terrain is rough, we will have to go for the multi-legged robots and if the terrain is in between, that is, it is neither very smooth nor very rough, then we will have to go for the tracked vehicle. Now, in experiment 2, we discuss the working principle of a tracked mobile manipulator and we have seen how it does work. And today in experiment 3, we are going to carry out the study on a hexapod that is, a six-legged robot. Now, these are the concepts which we are going to be dealt in this particular experiment.

I will give a brief introduction to the problem, that is, the problem related to the path planning and gait planning of a hexapod robot or a six-legged robot. I will be discussing the setup, which we are going to use to carry out the experiment. We will also see the specifications used while developing this particular experimental setup. The aims and objectives will also be discussed point-wise and based on which, the task of real experiments will be designed and real experiments will be conducted. Now, based on this particular, the experiments conducted, we will try to draw some inferences from the experiments. To carry out these experiments, some precautions are to be taken, those things we are going to discuss in details.

We are also going to discuss some possible applications of this type of six-legged robot and at the end some references will be given to get more information regarding this experimental setup and the robot. Now, let me start with the introduction. Now, this six-legged robot is one of the most popular forms of mobile robot and this is known as a hexapod. Now, as I have already mentioned that this particular hexapod is a multi-legged like six-legged robot, which can negotiate the rough terrain. Now, if you see the different types of multi-legged robots we use, we use six-legged robot like this with the help of which we are going to carry out experiment today.

We also have eight-legged robots. Now, these six-legged robots and eight-legged robots look-wise similar to the insects and this six-legged robot could be almost similar to a spider. Now, on the other hand, we have got the four-legged robots like animals, we also have the two-legged robots like humanoid. So, we have got all different types of multi-legged robots, but here, we are going to consider today only a six-legged robot. Now, this particular six-legged robot will be able to handle the rough terrain, it will also be able to negotiate or climb through small staircase, small height staircase and we will be conducting

experiment to show that it can negotiate the staircases.

Now, to perform some pre-specified task, a six-legged robot will have to make its path planning as well as the gait planning. The purpose of path planning is to make or decide a suitable path and this particular path planning as well as the gait planning is done based on the collected information of the environment with the help of cameras, with the help of your the sensors, the robot collect information and lot of calculations processing will be done and consequently, a safe plan of action that is nothing, but the path will be decided. And, based on the decided path the robot will have to generate the gait and gait is defined as the sequence of leg movement in coordination with its body movement. So, that this particular six-legged robot or the hexapod can walk or navigate after maintaining its balance. Now, maintaining the balance is a more difficult task.

So, this particular robot should be able to perform this task by consuming the minimum energy, but the most important thing is, it should generate some stable gait. That means, your the balance has to be maintained while navigating and that is actually one of the most difficult problem for a multi-legged robot. So, we will have to do the effective path planning, efficient gait planning so that this hexapod can perform its task in a very optimal sense. Now, to study on the gait planning, we take the help of one parameter. That particular parameter is known as the duty factor and it is denoted by beta (β).

Now, this beta (β) is defined as a ratio of the number of ground legs to that of the total number of legs. Now, this particular hexapod has got a total of six legs. That means, it has got six feet say. Now, if I just draw this particular six feet, I can also draw it in different ways, like here, I have considered one rectangle. Similarly, I can also consider more or less a circular thing and there also I can put all such the six legs.

This is another configuration for the six-legged robot. Now, when all the six legs are on the ground, then the duty factor beta (β) is nothing, but the number of legs put on the ground that is 6 divided by the total number of the ground feet, that is, 6. So, this is nothing, but 1.0. So, here the duty factor is 1.0.

That means, your all six legs are on the ground. Now, supposing that in a particular configuration say I have got only four legs which are on the ground. Supposing that this particular leg is on ground, then comes your this particular leg is on ground and let me consider that this particular leg is on ground, this particular foot is on ground. If it is so, then I have got only four feet lying on the ground. So, 4 divided by 6, that is, two-third that will be equal to the beta (β).

And, let me consider another configuration where only three feet are on the ground supposing that this is on the ground, this is in air, this is on the ground, this is in air and this is on the ground. Now, if it is so, then here the beta (β) will be equal to 3 divided by 6 and that is nothing, but half. Now, depending on this particular value of beta (β), that is the duty

factor. So, a particular gait pattern will be developed by this particular the hexapod or the six legged robot. Now, another thing we will have to remember and which I have already mentioned that is one of the most important thing while navigating, that is how to maintain that particular the balance.

Now, this six legged robot or the eight legged robot it could be either statically stable and it could be dynamically stable also. So, in general this six legged robot, eight legged robot, four legged robot there is a chance of static balance, static stability also. But, whenever we consider a two legged robot like humanoid robot there is no concept of static balance there which I will be discussing after some time with another experiment, then there we will have to consider the concept of the dynamic balance only. But, here, as I told that this six legged robot, there is a chance of static balance. So, how to determine the static balance? Let me consider that beta (β) equals to half that means, your only three feet are on the ground out of six.

So, this is in ground, this is also in ground, this is also in ground. So, with the help of these three ground feet if I just draw the support polygon for this particular the hexapod. So, I will be getting this type of support polygon. So, this support polygon will be some sort of triangle and what we do is, we try to find out the center of mass of this particular the six legged robot. Now, supposing that the center of mass is found to be located here.

So, what we do is from this particular point say O, we draw perpendicular to each of the sides that means, your if I draw perpendicular like this. So, I will be getting this particular distance is a d1. Similarly, if I draw the perpendicular here, so, I will be getting distance d2 and similarly if I draw the perpendicular here, so, I will be getting the distance d3. Now, I compare d1, d2 and d3 and find out the minimum out of these three d values. Now, the minimum of these three d values will be considered as stability balance margin.

So, let me repeat the minimum of three d values is nothing, but the stability margin. So, we try to find out that particular stability margin. So, that during the navigation that this six legged robot or the hexapod should be in stable configuration. Similarly, if I consider that beta (β) equals to two-third that means, your 4 feet are on the ground out of 6. So, in that case, so, this will be the support polygon and you try to find out the center of mass, supposing that this is the center of mass.

So, from here you draw all the perpendicular to the sides and once again you try to find out out of all such d like d1, d2, d3 and d4 which one is the minimum and that particular minimum value of d will be considered as stability margin. So, during navigation, so, this particular stability margin has to be determined and we will have to ensure that this particular vehicle is in stable zone. So, this is the way actually we can use the concept of duty factor to generate the stable gait. So, we have already seen that both path planning and the gait planning is very much essential while doing navigation of a six legged robot or the hexapod and the purpose of this particular experiment is to show you, how to do the path

planning, how to do the gait planning, so that it can solve the different problems related to your the navigation of this mobile robot, that is, the six legged robot. Now, during this navigation as I mentioned that this particular hexapod will have to collect information of the environment.

It collects information with the help of your the camera mounted on it, with the help of sensors mounted on it and with the help of this collected information, this hexapod is going to make a plan of its path and gait, so that it can perform that particular task by maintaining the balance. Now, this hexapod should be able to trace a trajectory accurately by conceiving the minimum amount of energy and it should also be able to maintain the balance. Now, how to determine the amount of energy consumption? To determine the amount of energy consumption what we do is, at each of the joints we have got the motor say DC motor and we will have to use some energy. So, we sum them up to find out what could be the total amount of energy required and based on that the power rating for each of the motor will also be determined. Now, I am just going to discuss the different components of this particular your the setup which we are going to use.

Now, this hexa as I told, it looks like a spider and this is a small six legged robot developed by Wincross in the year 2016. So, this particular setup will be actually used during this particular your the experiment. Now, let me show you say one picture of this particular the the six-legged robot and if you see this picture of the six legged robot given here. So, you can see that. So, this is the six legged robot, which we are going to use, it consists of six legs.

So, leg 1, leg 2, 3, 4, 5 and 6 and it has got a body and each of the legs if you see it has got three joints and each joint you can see is having only one degree of freedom ok. And here we use a rotary joint like a revolute joint. So, on each of these particular legs you can see this is one leg. So, at each of these particular legs we have got three revolute joint in series and each of the joint is having only one degree of freedom. So, the leg is having the three degrees of freedom.

So, each of the six legs is having three degrees of freedom ok and if you see construction wise on each leg we have got how many moving links. So, this is your joint 1 say this is joint 2 say and we have got another joint and that is nothing, but is your joint 3. Now, here what you can see is your in between these three joints we have got two active links. So, one is this and another is this and this is the support link. So, this is actually connected to the ground.

So, at each of the legs I have got two moving links rather active links. So, I have got six such legs. So, the number of your the moving links will be how much 6 multiplied by 12 and this body is considered as one more moving link sort of thing. So, we have got 13 such moving links ok. Now, if I just take the help of the Grubler's Criterion.

So, I am just going to take the help of Grubler's Criterion to find out what could be the

mobility level of this particular the six-legged robot. Now, according to the Grubler's Criterion for determining the degrees of freedom or the mobility. So, we are trying to find out what could be the level of mobility for this hexapod robot. Now, this is a planar one. So, 3 multiplied by the number of active links.

If you remember for each of the legs we have got two active links there are six legs. So, 6 multiplied by 2 is 12 and the body is also considered as a the another link. So, we have got 13 such moving links ok. And, how many joints we have in total we have got two we have got three joints at each of the legs and each joint is having one degree of freedom. So, the moment we use only one degree of freedom.

So, each of the joint is going to offer how many constraint that is 3 minus 1 that is 2. So, two constraints are offered by one joint lying on a particular the leg and in a leg there are three such joints. So, 3 multiplied by 6 so many such constraint will be offered by a particular leg and we have got 6 such legs. So, this is nothing, but 39 minus 36. So, we have got 3 as the mobility levels or degrees of freedom of this particular your the 6 legged robot.

That means, your this is a planar a 6 legged robot. So, it will have only 3 degrees of freedom. So, it could be like your the movement along x , movement along y and there could be rotation about z or there could be the movement along x movement, along y and movement along say say z. So, this is the way actually this particular the 6 legged robot or the hexapod is going to work. So, it has got 3 degrees of freedom and the mobility level for this particular the mobile robot or the 6 legged robot is your 3.

Although we are using how many motors we have got how many joints each leg 3 joints there are 6 such leg. So, we have got 18 such joints each having 1 degree of freedom and at each of the joint we are using 1 servo-motor ok. So, we have got 18 such servo-motors. So, all such 18 servo-motors are to be controlled by following the closed loop control system. So, that the movement can be generated as accurately as possible.

Now, we have already mentioned that this particular 6 legged robot has got 1 inbuilt camera to collect information of the environment. It is also equipped with infrared and ultrasonic sensors to detect the obstacle and to determine what could be the distance between the robot and the obstacle if any, ok. Now, this particular hexa that is the 6 legged robot looks like a spider will be able to walk, it will able to dance at a particular the location, it will be able to create different types of gesture and pose. So, we will see that while carrying out the real experiment that we can generate all such movements. Now, this particular the robot will be controlled either using a mobile app or we can also use the graphical user display also just to control this particular the 6 legged robot.

Now, this robot is also having some LED lights like RGB LED lights and with the help of this, this robot will be able to generate the different lights, the lights of different colors ok. And, while operating on this particular robot, there is a possibility you will be getting 3 color

signal. If you get yellow that indicates that no Wi-Fi is connected. So, this you can see while carrying out the real experiment. If you see the blue color light, it indicates the hexapod is trying to connect to the Wi-Fi network and if you get the purple color light, now it is ready to connect.

So, all such things you can see while carrying out that your the real experiment. Now, this 6 legged robot or hexa is equipped with some speaker and microphone. So, it can also respond to the sound and speech. So, these are the description of this setup and we also have a few other information related to this particular the setup.

You can see that so this particular figure. So, it is going to show that your the hexa or the 6 legged robot. Here, you can see we have got a camera. This is the location of the camera, this is the top body and this is the head. You can see this particular camera we have. We also have some ultrasonic sensor here and we can also have some infrared sensor here.

So, on this particular your head part, we have got the camera, then comes your ultrasonic sensor and infrared sensor. So, with the help of this camera and sensor, it is going to collect information of the environment and we have got 6 legs. Each of the legs has got 3 joints. These are already discussed and this robot, this 6 legged robot, we have got some dimensions like in terms of the diameter of this particular robot like the circular thing. If you just expand it, what could be the maximum diameter? So, that you can find out.

We can also find out how much will be the maximum height possible for this particular the robot. So, all such things we can find out, we can determine from this particular your the dimension of the robot. So, we have got this charging block like your wireless charging, we can also connect and also do the charging also that possibility is there. Now, here I am just going to give some brief interaction regarding the hardware interface of this particular robot. Now, here for any robot or any electrical electronics device, there must be the ground.

So, this is your the ground connections and ADC is your analog to digital converter, that is also required. There are a few USB ports here, then line in line out like just for connecting the different connectors. Then, we have got this I2C-SDA and I2C-SCL. SDA stands for the serial data line and SCL stand for the serial clock line and these particular things are used for the data transfer of the master and slave that particular the concept. Like we have got the we should have the provision for data transfer between the master and slave and this particular data transfer is done through this SDA-SCL.

So, we have got one GPIO also that is nothing, but the general purpose input output and we have got an I2C-Sinter integrated circuit. So, this is in short the hardware interfaces. Now, quickly let me try to revisit what are the different components of this particular the experimental setup. Now, you have seen the picture that this particular hexa has got a body and this body is actually made of plastic, rigid plastic and this rigid plastic inside that

particular cover we have got all electronic circuits, electrical circuits, we have got camera, we have got all sensors are mounted there only inside the body. We have got six legs each leg consists of once again the hard plastic sort of things and as I mentioned at each of the legs there are three revolute joints and each joint is having one degree of freedom.

We have got 18 servo motors because in total we have got 18 joints and to control the movement at each of the joints we have got one servo-motor and by definition we know that this servo-motor is actually a motor having the closed loop control system, where there will be a chance of error compensation. So, very accurately we can generate the movement. We have got 18 such servo-motors. We have got the microcontroller and this particular microcontroller is nothing, but the brain for this particular the robot and we will see that using this particular brain it will be able to do both path planning as well as gait planning, which are required to solve a particular task in a very efficient way, ok. So, we have got ARM Cortex-M4 microcontroller which is served as the brain for this particular the robot.

We have got a few sensors infrared and your ultrasonic sensor just to find out the distance between the robot and the obstacle if any and it will also try to find out the geometry or the age of that particular the obstacle, so that it can do its path planning and gait planning. And of course, we have got the rechargeable your lithium ion battery which provides that particular the required energy. We have got the speaker and microphone built in this particular the robot. So, we can respond to sound it can respond to sound and speech.

So, it is also possible. We have got the a few LED lights as I discussed, ok. We have got the different colors and different colors of this LED indicates the different meaning. Then, as I told that we can use one mobile app just to carry out this particular the experiment. We can also the graphical user interface also to control this particular the robot. So, now, we are going to concentrate on the specifications of this particular the setup.

Now, let me concentrate on the size of the robot. The size is decided by the diameter like if we consider that the base of that particular robot is going to trace one circle. So, its diameter is 20 inches and the maximum height is 4.7 inches, ok. Then operating environment. So, this particular robot will be able to walk in the temperature range of 10 to 35 degree centigrade and operating altitude is a tested up to 6562 feet, ok.

So, these are the operating environment. Then the hardware interface we also discussed a little bit a few minutes ago. We have got USB that 2.0, 3.5 millimeter audio line in audio, then 3.5 millimeter audio line out. We also discussed we have got GPIO and we have got ADC also analog to digital converter. Then 5 volt power or output 3.3 volt power output. Then for this particular charging purpose we have got the AC-DC adapter unit and its operating voltage is your 100 to 240 volt.

Then, rated frequency is 50 to 60 hertz, then we have got the AC-DC adapter. So, that we

can reduce the voltage to 9 volt. We have got the wired charging system and wireless charging system. So, if we go for the wired charging then it takes about 2.5 hours for the full charge, then wireless charging time is more 4.5 hours. We have got the wireless communication like Wi-Fi communication we generally use then IEEE 802. So, that type of wireless connections are also used. We have got the distance measuring sensor and that means, your we can use some sort of your ultrasonic sensor to measure the distance. We can also use infrared emitting sensor also to measure and collect information of the edges, the geometry, the distance all such things.

The overall weight of this particular robot is about 1.55 kg. Then we have got the visual system like we have got the sensor then comes your the field of view is about 70 degrees. The range of lens motion it is 360 degree, endless spin we can go for. We have got the aperture distortion and all such things are also specified. The resolution is also given here as 1 0 1 2 8 0 cross 720. Then shooting mode we can take photo, we can do recording of the videos, then recording resolution is your 720p, then infrared night vision is also available.

So, this particular robot can be used even in the dark atmosphere. Now, with this let me discuss the aims and objectives of this particular the experiment. So, we are going to carry out a few experiments like we are going to vary the height of the hexapod and hexapod will be varying its height standing at a particular location. Then we go for the navigation of this hexapod on the plane surface in the forward and backward direction. So, this hexapod should also be able to take the turn as the situation demands and it should also be able to follow some curve path beside the straight path. It can climb through the small height that means, it can negotiate some sort of the staircase, staircase with small height and it can also perform some operations like dancing and that type of thing so that it becomes very interesting to the children also ok.

And, while dancing, it can change its speed, it can dance at slow speed, medium speed as well as your the high speed. Now, I am just going for the carrying out the real experiment like how to carry out the real experiment. Now, as we have mentioned that this real experiment or the control of the robot can be done with the help of one mobile app and it can also be done using one graphical user interface also. Now, here it shows one picture of a mobile app like if you are going to use a mobile app to control this your the hexapod.

So, these are the things which will have to do. Now, this number 1 here on this particular picture that is camera on and off. So, we can put the camera on and off by pressing this particular the button. Then serial number 2 we have got the control gait like if you want to control the gait, we will have to take the help of your this particular the button. Then comes your control movement direction.

So, the direction can be actually selected here. So, I can move along this particular direction or towards the left towards the top or bottom. So, here we can select with the help of your the control movement direction with the help of this button. Then we have got the ground

clearance. So, ground clearance can also be adjusted with the help of this particular button.

Then comes your conduct single behavior. So, here actually there are a few. So, we can we can select it with the help of this we can select the different behaviors, one at a time back to the launcher. So, this is the actually one button we have. Then comes your head spinning. The robot can do the spinning of the head and that can be controlled with the help of your this particular the button. Then the yawing of the body, yaw you know that that is nothing, but the rotation about an axis. So, with the help of this particular, this button we can also actually do this particular yawing control. Then the control body pitching. So, pitching is another movement like movement about another axis.

So, we can use this particular for the pitching purpose. Then we have got the collected photo album if you want to have a look. So, we can take the help of this the shutter is this. So, if you want to take the picture of a particular environment we can use it.

Then photos and record videos. So, we can take the help of this particular the button. Then if you are going to use this particular robot in dark environment. So, we will have to go for the night vision mode with the help of this particular the button. So, on this mobile app all such switches buttons will be getting and by properly selecting the appropriate the buttons we can control the movement of this particular the robot. Now, we are planning to do the real experiments and while carrying out the real experiment these are the 6 tasks which we are going to carry out.

The task 1 we are going to vary the height of the hexa-pod kept at a fixed location. So, the hexa-pod will be kept at a fixed location and then its height will be varied by using the appropriate button on the mobile app. The task 2 is the navigation in forward and backward direction. So, on the plane surface the robot will be able to follow more or less a straight path in the forward direction and in the backward direction. Then task 3 is the turning motion.

So, at a particular location the robot can take the clockwise or the anticlockwise turn. Then task 4 is the navigation of this particular robot through the curve path. So, similar to the straight path it can also take some curve path, non-linear curve and it can work. Task 6 is staircase ascending. So, during the experiment one environment will be created and you will see that this particular hexa-pod will be able to ascend the staircase and at the end with the successful implementation of all the tasks, after carrying out all the tasks successfully, as if the robot will become very happy and it will start dancing, that is the final task, that is your the task 6. Thank you.