Lecture 02: Experiment 01: Teaching of Serial Manipulator

I welcome you all to experiment 1 and here, we are going to deal with the teaching of a serial manipulator. Now, the serial manipulator which I am going to consider here is nothing, but the UR-5. So, this particular serial manipulator is the UR-5 manipulator. You can see that it has got one teach pendant. So, this is nothing, but the teach pendant and it has got a controller or a director, ok. So, to control this UR-5, that is a serial manipulator, I am just going to use a teach pendant and it will be controlled by a controller box or this is nothing, but the director. And the purpose of teaching as I told that how to give instruction to the robot. Now, here in this experiment 1, we are going to discuss in details like how to give instruction to a particular robot. Now, this is actually the structure or the planning of our discussion in this experiment.

I will be giving a brief introduction to this particular experiment, that is experiment 1 related to the teaching of a serial manipulator. I will be giving a brief description to this particular robot, that is UR-5. I will concentrate on the specifications for this particular robot with the help of which we are going to conduct the experiments. The aims and objectives of this particular experiment will be discussed. Now, here with the help of this serial manipulator, we are going to conduct 3 tasks, which I will be discussing in details.

The real experiment will be conducted on this particular robot related to these 3 tasks. Some inferences will be drawn from these experiments and a few precautions are to be taken while carrying out this particular experiment and those will be discussed in details. Some possible applications of this type of robot will be discussed in details and at the end, some reference details will be given. Now, to start with this serial manipulator, it is nothing, but a robot with fixed base and here, all the

rigid links and the joints used to connect the rigid links they are in series. Now, if you see in robotics, in fact, we have got a few rigid links.

For example, here you can see in this UR-5, we have got the fixed base and in between the fixed base and this particular part, we have got one joint here, that is a rotary joint. Now, this particular link and that particular link in between we have got another joint here. Similarly, there are a few other links and in between the two links, there will be a joint. Now, if you see the joint in robots, the joints could be of two types. We have got the linear joints and we have got the rotary joints.

Now, these linear joints could be of two types further. So, there could be prismatic joint or there could be some sort of joint that is called the joint having the circular cross section that is called the sliding joint. So, let me just draw that particular joint supposing that I have got one part like this. Now, here I have got say one component and there is another component I am just going to draw it here. So, this type of things I have and this sliding member is going to slide here.

So, this type of joint is known as the prismatic joint and this is a linear joint. Now, there could be sliding joint also supposing that I have got one fixed member something like this and it has got a groove like this and here I have got a member, the member might be looking like this and this member is going to slide here. So, this type of linear joint is known as the cyclic joint. So, there could be prismatic joint or there could be the sliding joint. So, these two joints are nothing, but the linear joint.

On the other hand, there could be the rotary joint. So, this rotary joint could be of two types, one is called the revolute joint. For example, here you can see say here this particular link I have got one link here, I have got another link here. So, in between the two links, we have got a joint here. Now, here the axis of the output link is something like this and this is the input link say and the axis about which I am taking the rotation is

something like this.

So, the axis of the output link and the axis about which I am taking the rotation, if this particular angle is your 90 degree, that type of rotary joint is known as the revolute joint. On the other hand, here you can see this is the fixed base and this is the moving link and here I have got a joint and the axis of the output link is something like this and the axis about which I am taking the rotation with the help of this particular joint, they are coinciding and the angle between them is 0 degree. This type of rotary joint is known as the twisting joint. So, just to repeat the joints, the robotic joints could be of two types, it could be either the linear joint or the rotary joint. The linear joint could be either the prismatic joint or the sliding joint.

In prismatic joint, the sliding member will have either the square or the rectangular cross section. For example, it has got one rectangle or square cross section. On the other hand, the sliding joint will have some sort of the circular cross section. So, these two are the linear joints and we have got two different types of rotary joints. One is called the revolute joint, for example, this joint is a revolute joint, another is called the twisting joint.

So, this is the twisting joint. So, here in this particular robot UR-5, we have got three revolute joint and three twisting joint. The joints are in series and each having one degree of freedom. So, this particular serial manipulator, that is, UR-5 has got 6 degrees of freedom. Now, remember in robotics, we use two other different types of joints also.

One is called the Hooke joint, it is having 2 degrees of freedom, both are rotary. We have got another rotary joint, that is called the spherical joint or the ball and socket joint and that is having the 3 degrees of freedom. Now, here this is a serial manipulator, not like your parallel manipulator. In parallel manipulator, the links or the joints are in parallel and in serial

manipulator, here the links and joints are in series. And you can see that this is the fixed base.

So, this part is the fixed and there are a few links and joints and here I can connect that the tool or the end effector and this type of mechanism is called the open kinematic chain mechanism. So, open kinematic chain mechanism, this end is fixed, other end is free and this is known as the open kinematic chain. And here, as I told that each of the joints is a rotary joint and this particular rotary joint, there will be a motor. We use the brushless DC motor and of course, on the output shaft of the DC motor, there must be gearbox, there must be a rotary encoder just to measure the angular displacement and there must be a braking mechanism. We use different types of grippers, the end effector depending on the requirement of the task and how to carry out the analysis? To carry out the analysis at each of the joints, we try to assign some coordinate system according to the Denavit-Hartenberg parameters or Denavit-Hartenberg notations and once we have assigned the coordinates at each of these particular joints, we try to carry out its kinematic analysis.

So, we try to conduct the forward kinematics and the inverse kinematics. In forward kinematics, what we do is, we try to represent the position and orientation of this end effector with respect to the base coordinate frame. And in inverse kinematics, we just do the reverse as if the position and orientation of the end effector are known and we will have to find out what could be the joint angles. Now, I am just going to concentrate on the teaching methods. As I told, the purpose of teaching is to provide instruction to the robot like how can you give the instruction that you start from a particular point, reach the goal through a number of intermediate points.

So, this teaching method could be either online methods or there could be offline. In online teaching methods, while giving instruction to it, we are using the robot and in offline method, the robot is not used while giving teaching and generally, we take the help of some programming language. Now, these online methods, it could be either manual teaching or there could be some lead through teaching. So, those things we are going to discuss in details. Now, this manual teaching as I told that this online teaching, we are using this particular the robot while teaching it.

Now, we use the online teaching for the point-to-point task and how to use this point-to-point task and what do you mean by the point-to-point task? Now, here supposing that I have got a steel plate and on this particular steel plate, I will have to make some drilled hole at some pre-specified locations. So, this particular steel plate is in X, Y and Z say and here at location 1, I will have to make one drilled hole in location 2, another drilled hole. So, what we do is, we used one twisted drill bit and this particular drill bit is controlled by the serial manipulator like that UR-5. Now, to make this particular the drilled hole, the tip of the twisted drill bit should be able to touch the center of the hole and after that, this drill bit should be rotated in the clockwise or say anticlockwise depending on the requirement. So, this is the way actually, we try to make drilled hole at some pre-specified location.

And once this particular hole is made at location 1, the tool is shifted to location 2 and we try to repeat the process. So, this type of task, where this particular part of the job has been done and the tool is withdrawn from the job, then we go to the second location is known as the point-to-point task. And here, to perform this point-to-point task, we take the help of your manual teaching and to perform this manual teaching, we use one teach pendant. This we are going to discuss in details. Now, I am just going to take another example.

Supposing that I have got a steel plate, another steel plate and on one side of a steel plate, say I will have to cut a complicated profile like this. So, this type of complicated profile, I will have to cut on one side of a steel

plate. So, how to cut this type of steel plate? So, what we do is, we try to take the help of a milling cutter and this particular milling cutter will be controlled by one serial manipulator, say UR-5. Now, while cutting this complicated profile on one side of a steel plate, this milling cutter will be rotated at the same time, it should be able to trace this complicated profile and this milling cutter will be gripped by the serial manipulator, say UR-5. Now, if I want to give this type of instruction to the robot to perform, we will have to take the help of your lead-through teaching and this particular task is nothing, but the continuous path task because the tool is in contact with the job continuously, ok.

And the tool is gripped by the serial manipulator, in the tool there must be a rotation and the tool should be able to trace that complicated profile. And here, how to solve it, how to teach? So, we take the help of one robot simulator or we can also use some specially designed teach pendant. Now, in robot simulator, that is actually another robot, which is kinematically equivalent to the main robot to be taught. So, I have got a robot, which has to be taught, I consider another robot side by side and the second robot is kinematically equivalent to the first robot. And in the first robot, which I am going to teach, it has got a few joints and at each of the joints, we have got the gear drive, we have got the brakes.

So, controlling that particular robot, which I am going to teach is very difficult. Then, how to give instruction to the robot that you follow this complicated profile? So, one of the ways could be if I just grip that the end-effector, which is nothing, but the milling cutter and if I trace this complicated profile in a particular cycle time and this particular cycle time, if it is divided into a large number of small segments and if I can find out all the joint angles for the robot, it has got 6 degrees of freedom, there are 6 joints. So, at each of the joints, we have got angular displacement θ_1, θ_2 up to θ_6. So, if I know the variation of θ_1, θ_2 up to θ_6, all the joints angles at the 6 joints, I will be able to control this particular task in a very efficient way. And while tracing this complicated

profile, if I can store those ϴ values of the joint angle values, I can give it to the main robot, which I am going to teach because the main robot I cannot move, I cannot move its end-effector, but the robot simulator which is kinematically equivalent to the main robot has got no gear drive, has got no brakes.

So, I can just grip and I can trace that complicated profile, ok. And while tracing that complicated profile at regular interval with the help of robot simulator, I can find out the variation of joint angle and those set of joint angles, I can use it for teaching the main robot, which I am going to teach. That is actually a method of the lead-through teaching using a robot simulator, which is a second robot kinematically equivalent to the main robot, which I am going to teach. But, here in this particular experiment, we are going to use the teach pendant only even to carry out the lead-through teaching. So, whenever we are going to conduct some experiment, the three experiments using this particular robot, we will be using the specially designed teach pendant only to perform this particular the experiment.

Now, to summarize this online teaching, it could be either manual teaching or lead-through teaching. And in offline, in fact, we have got the programming facility and while teaching or while giving instruction to the robot, we are not using the robot, instead we can write that particular the competitive program related to that particular task and once that particular the program is written, that is saved, that is compiled and once it is compiled, that is run on the main robot. Now, here if you see for this UR-5, we have got a few other facilities also for offline. For example, you can see that we can use one offline simulator for offline method of teaching. So, in this particular UR-5 developed by these Universal robots, this UR-5, we have got a simulation software and that is called UR-SIM.

So, with the help of this particular simulation software, we can provide the offline teaching to this particular the robot. And there are some other methods, for example, we can use some script-based control, we can use Python language just to give instruction to this particular robot in offline. So, this is the second possibility. There are a few other possibilities of offline teaching. For example, we can use the robot operating system, that is ROS.

ROS can be used to give offline teaching to this particular UR-5. There is another possibility, we can also use some PLC and HMI. PLC, we know programmable logic controller. So, we can use PLC or we can use HMI, that is, the Human Machine Interface to provide instruction to this particular the robot offline. So, these are the way, in fact, we can give offline teaching to this particular UR-5.

Now, I am just going to concentrate on the description of this particular robot with the help of which we are going to conduct the experiment. As I told that this particular UR-5, this is, in fact, one serial manipulator having six degrees of freedom and this is actually manufactured by one Danish manufacturer and this UR-5 is the universal robots 5. Now, here you can see that we have got the fixed base, then we have got one joint here, rotary joint like twisting joint, we have got another joint here, that is called the revolute joint. Similarly, we have got some other revolute joint here, we have got some revolute and twisting joint there also. So, we have got as I mentioned three revolute joint and three twisting joint, all six are rotary joint each having one degrees of freedom.

Now, this is the serial manipulator with the help of which we are going to perform the experiment and we have got one teach pendant. So, this is the teach pendant, which we are going to use and this robot has got one controller or the director. So, this is nothing, but the brain for this particular robot. Now, let me concentrate on the serial manipulator. Construction-wise, as I told that this consists of a few fixed links, the rigid links rather and two rigid links are joined by a joint and here we have got

a teach pendant that is nothing, but some sort of remote controller.

So, we have got the power button with the help of which we can switch it on or off and there is one emergency switch also. So, that if situation demands, we can switch off that particular robot and here you will see that we have got the display and on the display, there will be different buttons, different instructions and depending on the requirement, we can select so that we can control this UR-5 through this controller or the Director because the controller or Director consists of both software as well as hardware and this is nothing, but the brain for this particular robot, ok. So, this is in short the construction details of this particular serial manipulator UR-5, which we are going to use in this particular experiment. And these are the specifications like your it is as I told UR-5 that is the universal robot 5, the total weight is 18.4 kg of this whole robot, it has got 6 rotary joints as I told and its payload capacity is 5 kg.

That means, it can carry up to the 5 kg load, that is the end-effector can carry up to 5 kg load. The reach is 850 millimeter, ok. That means, if you just use all the joints in a particular extreme condition, each joint has got a range of movement and the maximum reach, which it can go up to is your 850 millimeter. The range of movement for each of the joints plus minus 360-degree, clockwise and anticlockwise. The speed for the joint maximum speed is 180-degree per second and the linear speed is your 1 meter per second.

The repeatability of the robot is plus minus 0.1 millimeter. That means, the same set of experiment if you conduct several times in a repeated mode. So, what is the precision with which it can reach that particular predefined position? The footprint that is 149 millimeter and this is actually the diameter. So, this is actually the footprint diameter. Then input output ports are there, input output power supply 24 volt, 2 ampere in control box, then 12 volt or 24 volt, 600 milliampere in total.

Power supply 100 to 240, then comes your 50 to 60 hertz. Power consumption is approximately 200 watt. Communication TCP IP, TCP is the transmission control protocol, IP is the internet protocol. So, this is actually the specification.

Programming we have got the graphical interface. So, we can go for the programming for this particular robot. We have got 12-inch touchscreen which is mounted, where we can write down the program and the calculated operating life is 35000 hours. So, these are the specifications of this particular robot with the help of which we are going to conduct the experiment. Now, I am going to discuss the aims and objectives of this particular experiment 1, that is teaching of serial manipulator. Now, here in this particular experiment, we are going to conduct 3 tasks.

Task 1, how to control UR-5 with the help of the teach pendant, that is a remote controller. The task 2 is how to do programming of UR-5 using the teach pendant to perform a task that is nothing, but the peak and place type of operation. And task 3, how to do the programming of this UR-5 using the teach pendant for a continuous path task. So, this task, I am just going to discuss briefly and these experiments will be conducted on the real experience of the robot. So, let me start with the task 1, that is how to control UR-5 with the help of a teach pendant.

And as I told, the real experiment will be conducted and shown after this lecture. So, here, we are going to use a teach pendant. You can see that this is nothing, but the screen for a teach pendant, which is a remote controller. It is almost similar to the remote controller used in our TV, but it is a more sophisticated one, ok.

You can see that it has got one button. So, this particular button is the power button. So, you can put it off and on, ok. The next is we have got one emergency button here, the red one, which can be used if it is required to make sudden stop of this particular robot. And we have got a

few individual joint motion keys. Now, if you remember this UR-5 has got 6 joints and the joint angles are nothing, but Θ_1, Θ_2 up to Θ_6 because all the joints are rotary in nature, ok.

So, here, you can see that we have got the individual motion keys, ok. So, you can see that 1, 2, 3, 4, 5, 6. So, each of these particular joints can be their rotation or the movement can be controlled with the help of these keys, ok. And once you are controlling or changing the numerical values, it will be displayed on the TC position and orientation display. So, here, you will be getting that particular display of the changed angular rotation or angular movement.

The moment you select one set of Θ_1, Θ_2 up to Θ_6, the configuration you can see on this particular screen, ok, the configuration which I am going to reach. We have got TCP navigation keys along the base coordinate, that is, along X-axis, Y-axis and Z-axis, ok. And TCP is nothing, but Transmission Control Protocol, the short form Transmission Control Protocol is TCP. So, TCP navigation keys along the base X, Y and Z, ok, so with the help of this, we can control. Similarly, the TCP rotation keys about the tool coordinates like rotation about X, rotation about Y, rotation about Z, so that will be actually controlled with the help of this, ok.

So, if you see the display of this teach pendant, ok, so all such things will be getting and whenever we are going to show the real experiment using the teach pendant, all such things will be shown to you in details. Now, the modes of operating UR-5 using the teach pendant, ok, so this is another display of this particular the teach pendant which you can have a look, ok, and all such things will be shown while carrying out the real experiment. So, here if you see the operating modes, so it is written run program, then program robot, setup robot, shutdown robot and so on. Now, this run program, this particular the mode is used to run the existing saved program. So, I have written a program to perform a particular task,

I have saved that particular program and I have already compiled and now I want to run it.

So, I just go for this mode that is called the run mode, you can see that there will be run mode here, ok. The next is a program mode. So, what you can do is, if you have got some existing program, you can further modify it, edit it or you can start with a new program, ok, and you can once again save it and compile it with the help of this teach pendant that is called the program robot mode, you can see that. Then comes your the setup robot, we set the passwords, upgrade the software, request, support, calibrate the touch screen with the help of this setup robot, you can see this particular mode, ok.

Then comes your the shutdown robot. So, if you want to switch off or the power of the robot arm, we will have to go for that particular the shutdown mode. So, these are the modes available on the teach pendant, which will be showed to you while carrying out the real experiment. Now, let us concentrate on this particular the program mode. So, how to write down this particular program? You can see that this is the screen of your the teach pendant and here it is written program mode, ok.

And in this program mode, I can use some programming commands, ok. For example, say we have got the programming commands like move, waypoint, wait, set, pop-up, halt. You can also see here on the screen of the teach pendant, we have got move, waypoint, wait, set, pop-up, halt, etcetera, ok. And now, I am just going to discuss a little bit in more details, but all such things will be discussed in much more detail while carrying out the real experiment. Now, let us concentrate on the move commands.

Now, these move commands could be of different types. For example, move j, the moment we are using this particular command move j, the

robot will follow the fastest path between the waypoints, but non-linear in nature. Are you getting my point? What does it mean? So, between the two waypoints, it will try to find out the fastest path and which could be non-linear also. So, if we use this particular command, that is, move j, then comes your move l. So, this particular command is used just to create the linear motion of the TCP. If you want to generate the linear motion, we will have to go for this command, that is, the move l.

Then comes your move p. So, this particular command is used when we want to get a fixed speed of the TCP. For example, some task I want to perform with some predefined fixed speed. So, it is better to go for this type of command. Then move c, this is used to generate the circular motion of the TCP. So, if you want to generate some circular motion, we generally go for this type of command.

So, these are the options available on the teach pendant with the help of which, this particular program can be written to perform some pre-specified tasks. Now, this waypoint, I have already mentioned, this waypoint is nothing but the location and orientation information in Cartesian coordinate system. You know, a 3D point in 3D space, if you want to represent, we need its position and orientation information, ok. That means, a 3D object for example, say this is a 3D object. So, if I want to indicate its position and orientation in 3D space, I need to know its center CG, its position and the orientation rotation about X, Y and Z, ok.

So, all such things, I will have to mention, ok, through this waypoint. Then, comes your wait, it creates pause of the input output signal, then comes your the set either the digital or analog output will be set, then comes the pop-up model, then the halt, it will stop the execution, the program execution will be stopped, if we use this particular command. Now, with this, let me concentrate on the task 2 now. Now, the task 1, whatever I discussed in brief, will be shown to all of you in details while carrying out the experiment. The task 2 is programming of UR-5 using

teach pendant for pick and place type of operation.

Let me consider a very simple operation. Supposing that my hand is nothing, but UR-5, a serial manipulator, ok. And I have got my own coordinate system, ok. The position and orientation of the tip of my hand is known with respect to my own coordinate system. Now, supposing that I have got one say one object, say one object in 3D space, ok.

Say this particular object in 3D space, ok. And to represent this particular object, which I am going to grip and carry to another location, I should know the position and orientation of this particular object with respect to my world coordinate system. And what is this pick and place operation? This is my serial manipulator UR-5, my hand is UR-5. So, I am just going to bring my end-effector or the finger and it is going to grip it, the object. And once it is gripped, I have got another location here, say I have got a bin or a bucket here, ok. And its position and orientation are also known with respect to my base coordinate system, my body coordinate system.

So, what I do is starting from here, this particular object I am just going to bring it and I am just going to place it here and release it, ok. So, that is, let me repeat it. So, the object is here in 3D space, I am just going to grip it, I am just picking it and my hand is the UR-5 serial manipulator, ok. So, I am just going to follow a particular trajectory to reach that particular goal that is nothing, but a bin or a bucket here, whose position and orientations are also known with respect to the base coordinate frame and I am just going to place it here.

So, it is pick and place type of operation. So, how to write down the program? Using this Teach pendant, how to write down the program? So, that you can give this particular command to the serial manipulator that you perform this pick and place type of operation, ok. So, that will be some sort of the task 2. Now, this task 2, all the programming steps

will be discussed in details while carrying out the real experiment in the laboratory, ok. So, you will be getting all such steps further, how to carry out the real experiment related to this pick and place type of operation. So, these steps will be discussed once again in details while carrying out the real experiment and a real experiment will be conducted by following each of these particular steps.

Similarly, we have got a few other steps to conduct the task 2. Now, I am just going for the task 3. What is that? The programming of UR-5 using Teach pendant for continuous path task planning. Continuous path task, I have already discussed like the tool should be in touch with the job continuously, ok. That is nothing, but the continuous path task.

Now, here with the help of this UR-5, the task which we are going to solve is as follows. Supposing that you can see this particular picture at the end effector or the tip of that particular manipulator, we have put one marker, one pen sort of thing, ok. And with the help of this particular marker, how to give instruction to the robot that you draw one say rectangle or you draw one say square or a circle on a 2D plane. You can see that on the 2D plane, that is the plane of the table or plane of the paper. So, this particular robot is going to draw some geometry. Are you getting my point? So, how to give this type of teaching to this UR-5 with the help of Teach pendant, that will be your task 3.

Now, here all the steps to be conducted to perform this particular experiment will be discussed in details, while carrying out the real experiment, ok. So, these steps will be discussed in much more details while carrying out the real experiments in the laboratory. So, all such steps will be discussed once again in details. So, with this, in fact, we are going to show you the real experiments on all these three tasks, task 1, task 2 and task 3 on the real robot, that is UR-5.

So, now you have a look of the real experiments conducted to perform

these tasks on the UR-5. Please note that there is a small correction here. We have used one abbreviated term TCP and this TCP should stand for tool center point in place of transmission control protocol. Thank you.