Lecture 18 : Summary of the Course

Now, I am going to summarize the content of this particular NPTEL course on Experimental Robotics. Now, in this course, we have conducted experiments on five different robots. The first experiment, we conducted on the teaching of this serial manipulator. The second experiment was on control of the tracked mobile manipulator. The third experiment was on path and gait planning for this six-legged robot or the hexa-pod. The fourth experiment was on navigation of drone and the fifth experiment was on path and gait planning of this humanoid robot.

Now, with this, I am just going to put a summary for the whole course and once again to put the summary, I will try with the introduction, I gave to the course and its uniqueness. Then, we will try to remember whatever we discuss regarding the robots and robotics and then steps to be followed to develop one robot. And I am just going to discuss briefly as a summary of the five experiments conducted using five different robots and the outcome of this particular course that will be highlighted. Now, to start with introducing the course, this is a course on Experimental Robotics.

As I told that this particular course is unique in the sense that we use not the fundamentals or not only the fundamentals, but the applications of four modules of the robots and robotics, that is kinematics, dynamics, control scheme and intelligent issues. To make it even more clear, we use the fundamentals of all four modules of robotics, which are generally discussed and explained in the conventional course on robotics including my own NPTEL course on robotics. But this present NPTEL course on Experimental Robotics is slightly different in the sense, we use them all four modules, their fundamentals, but we tried to use it, we tried to see on their application sides to conduct some experiments related to the real robots, so that it can perform some real-world task. Now, here we started with the very definition of robots and robotics and robots are nothing, but multifunctional manipulators used to move the different parts and this is actually an automatic machine and this automatic machine can perform a variety of tasks. And robotics is actually the science, which deals with the issues related to design, development and application of robots.

If you see the literature, the robots are available in various forms like manipulators. Manipulators are nothing, but the robots with fixed base, it could be a serial manipulator or it could be parallel manipulator. In serial manipulator, the links the joints are put in series, in parallel manipulator, the links and the joints are put in parallel. So, we have got the manipulators, we have got different types of mobile robots, we have got the tracked vehicles, we have got the wheeled robots, multi-legged robots, multi-legged robots could be of two-legged robots, four-legged robot, six-legged robot, eight-legged robots, we have got unmanned aerial vehicles like drones also and there are some other types of robots. So, here we have done five experiments using five different robots and we also discussed the steps to be followed to design and develop one robot.

Now, the robot is designed and developed to perform some pre-specified tasks. So, depending on the task, we try to prepare the initial design or the draft design of a robot. We carry out the analysis like kinematic analysis, dynamic analysis and based on this kinematic and dynamic analysis, we try to formulate as an optimization problem. We also consider the control scheme also in the optimization module and considering everything, we try to find out what could be the optimal design of a particular robot. And based on this particular optimal design, we prepare the final drawing for manufacturing of the components.

We do the assembly and once that particular assembly is done, we test their preliminary performances and once it is found to work, we try to inject intelligence to the robot. We can also teach the robot a few instructions to be followed by the robot and once it is found to be suitable in the lab environment, we just try to go for the real-world application of these particular robots. Now, as I told that we carried out five different experiments using five different robots and this particular the experiments and the robots have been selected in such a way, so that we can cover a very wide range of the applications of robots. And once again, we will summarize all such experiments one after another and as I told that this particular course, there is no prerequisite. It will be the four weeks course, it is suitable for the UG and PhD students including PhD, even the highest school children can also take it, there is no such complex mathematics, which I consider in my earlier NPTEL course on robotic conventional course on robotics.

And this particular course on experimental robotics is also suitable and useful to the practicing engineers and the outcome of this particular course will be discussed towards the end of my today's lecture. So, let me try to concentrate once again in short the different experiments, which we conducted. The first experiment, we conducted is on teaching of serial manipulator. The purpose of teaching is to give instruction to the robot and we are just going to give instruction either in offline mode or in online mode. In online mode, we are going to use the robot while teaching it and in offline mode, we are not going to use the robot while giving instruction.

And once the instruction is given, then the program is run, compiled and run and during the running, we are using this particular robot and that is called the offline teaching. Now, here, we are going to use one serial manipulator having say 6 degrees of freedom. So, we discussed that robots are having generally two types of joints, one is called the linear joints and we can have the rotary joints. Now, the linear joints, it could be either prismatic joint, or there could be some sort of sliding joint and the difference between the prismatic joint and sliding joint, the sliding member will have either square or rectangular cross-section for the prismatic joint. On the other hand, the sliding member will have circular cross-section for this particular the sliding joint.

Now, this rotary joints, it could be of two types, one is called the revolute joint and we

have got the twisting joint. So, here in this particular robot, we have got three revolute and three twisting joints. So, with the help of these six joints, this robot, it is a serial manipulator. So, it will have 6 degrees of freedom. So, we tried to control each of these particular joints.

For example, say we have got a few joints here, for example, here there is one joint twisting joint, we have got one revolute here, another revolute here and here we have got like your one revolute and two twisting and each of the joints how to control to perform the different task, that is, type of experiments we conducted. Now, the purpose of teaching is to give instruction to the robot, but not to make it intelligent. So, if you want to incorporate intelligence to the robot, which we have done in some other experiment, we will have to take a slightly different method. But by teaching, we can make a robot a taught robot, but we cannot make it intelligent. Now, besides this in some of the robotic connections, we use the joint having 2 degrees of freedom that is called your hook joint or the universal joint having 2 degrees of freedom.

We also use the spherical joint or the ball and socket joint having 3 degrees of freedom. So, these your Hook joint and spherical joints are not used here. Generally, both types of the joints are used in parallel manipulator. So, with the help of this particular the serial manipulator, this is called the UR-5, the name of this particular serial manipulator is UR-5, we conducted 3 tasks, real experiment. So, task was controlling UR-5 with the help of a remote controller.

The name of the remote controller is teach pendant, we have discussed in details, its construction details also and how to control the movement of the different joints with the help of your the teach pendant or remote controller. In task 2, with the help of this teach pendant, we wrote some program just to tackle the pick and place type of task, that is nothing, but the point to point task. Then in task 3, we wrote some program using the teach pendant just to perform some continuous path task, where the tool will be in touch with the job continuously. So, we discussed in details the difference between the point to point task that is your point to point task and your continuous path task that is, CP. So, we have discussed and we made the program using the teach pendant both for the pick and place type of operation and continuous path task and accordingly, we could control that particular the serial manipulator, that is, UR-5.

So, this was the first experiment. The second experiment was on the control of tracked mobile manipulator. The purpose of this tracked mobile manipulator I have already discussed. So, we use the tracked part, this is the tracked part and this is the serial manipulator mounted on the robot. So, this tracked part or the tracked vehicle is going to provide the mobility to the robot and this serial manipulator is actually going to give some workspace and if I just combine this, I will be getting the enhanced workspace or larger workspace because now this available workspace has got some mobility.

So, we will be getting the larger workspace. So, that is actually the purpose for going for the tracked mobile manipulator, where the two separate robots we are going to combine and this tracked vehicle is generally preferred for the rough terrain like the field because there the field robots may not be able to move properly. So, this particular tracked mobile manipulator can be used as agriculture robot and there are some other applications also. So, in this particular experiment what we did? So, that I am going to tell you task wise. The task 1, we carried out navigation of this tracked mobile manipulator.

So, that we can move it forward and backward and this particular robot can also take turn. Then task 2 is control of different joints of the serial manipulator. So, serial manipulator has got a few joints, rotary joints and this 5 joints of the serial manipulator individually we can control. Then, task 3, this particular tracked mobile manipulator has been used as pesticide spraying robot in the real agricultural field. So, in task 3, the robot with the help of a mounted camera will try to take the picture of the plant leaves, it will do image analysis to find out whether it is suffering from any disease.

If it suffers from a disease, it will try to find out from which disease it is suffering from and accordingly it will select the appropriate pesticide and it will do the spraying of the pesticides. So, these are the experiments which we conducted and this robot will be able to handle some sort of rough terrain also. The third experiment that is on the path and gait planning of a 6-legged robot. So, this is the 6-legged robot with the help of which we conducted the experiment. The purpose of path planning is to decide the course of action and the purpose of gait planning is to decide the sequence of leg movements in coordinating with the body movement, so that it can work, it can perform that particular task.

Now, this particular 6-legged robot has got 6 legs, each leg has got 3 joints, 3 rotary joints. So, each leg has got 3 degrees of freedom, but here the legs are placed in parallel, but not in series. So, this particular robot will not have 3 multiplied by 6, 18 degrees of freedom. It is different, it is not a serial connection, it is a parallel connection and using the Grubler's criterion, which I discussed that mobility or the degrees of freedom of this particular 6-legged robot is found to be equal to only 3. So, using the Grubler's criterion, we can find out that this particular 6-legged robot will have mobility levels of 3 only.

Now, with the help of this particular 6-legged robot, we carried out some experiment and before I go for discussing those tasks, let me tell you that this particular robot is equipped with some camera and a few sensor like ultrasonic sensor, infrared sensor, so that it can collect information of the environment and accordingly it can take its action. So, you can see that say that this particular robot is little bit intelligent and it is autonomous too. So, the task which we carried out with the help of these particular robots, so at a particular location of the hexapod, we tried to vary the height of the hexapod in task 1 and in task 2, the robot is instructed to move in the forward and backward directions. Then we consider the turning motion of the 6-legged robot in task 3, then task 4 navigation of this particular

robot through some curved path, then we consider the staircase ascending in task 5 and at the end as if the robot could perform well in all the tasks, so it ends with its dancing motion. So, these are the tasks actually which we conducted with the help of this particular the hexapod.

Then comes the experiment 4 and that is related to the navigation of a drone and as I told the drone is nothing but an UAV. So, this UAV that is unmanned aerial vehicle, there is no onboard human pilot in this particular UAV or drone and instead we can control this particular the navigation of this drone wirelessly and remotely. So, remotely we can control or we can also make this particular drone autonomous. So, it can take its decision of its own and it can navigate depending on the requirement. Now, here we are going to use one quadcopter, there are 4 propellers and this particular drone we have used for carrying out the real experiment and this is the robot controller used for this particular the drone.

Once again the drone is equipped with different types of cameras, different types of sensors, it has got the wireless module. So, we can control it wirelessly, we can get we can send command wirelessly and this particular robot can also take its own decision. So, it is intelligent and autonomous too. Now, with the help of this particular drone, we have conducted a number of experiments. The task 1 was maneuvering from one starting point to another goal point through some intermediate points.

We took the help of both manual piloting and autopiloting. Then task 2 is actually following a straight path. So, instruction will be given to the drone to follow a straight path and the drone is going to follow the straight path as accurately as possible. The next task, that is task 3 is related to circular path following. So, as the instructions are given, the drone is going to follow the circular path.

Then task 4 is tracking and tracing one human being. So, the drone will be taught to trace one human being and the way the human being is moving. So, the drone is going to track it and drone is also going to move as the human being walks or moves. Then task 5, some trajectory or path will be drawn on the control panel and the drone will try to follow it. So, these are the tasks, these are the experiments conducted on the drone.

Then comes your experiment 5, that is the path and gait planning of the human and robot. Now, we have already discussed several times the meaning for path planning and gait planning and why do you need a combined path and gait planning for the multi-legged robot, particularly your this humanoid robot. In fact, this combined path and gait planning we need for all the multi-legged robots. So, here in experiment 5, we use a NAO robot having 25 degrees of freedom.

You can see this is the NAO robot. So, we have got the joints like we have got the ankle joint here, we have got the knee joint here, we have got the hip joint here, then here also on this particular leg we have got the ankle joint, then comes your the knee joint and we have

got this hip joint also. So, there are some neck joints, two degrees of freedom and on the each of the hand we have got like a shoulder joint, elbow joint, wrist joint. There are some sensors, different sensors we have the touch sensor, here also we have got touch sensor or the tactile sensor, we have got the cameras here, we have got some other type of sensor, then we have got the speaker, then the different types of your sensor camera, then the different types of joints and this particular robot should be able to maintain its dynamic balance while performing a particular the task. Generally, for this humanoid robot, we want that it should be able to perform the task by consuming the minimum energy after maintaining the dynamic balance. So, with the help of this particular robot, these are the tasks which have been conducted.

So, task 1 is identification and movement of different joints of the robot. So, we are able to move the different joints of the robot with the help of your choreograph software and task 2 is forward and backward movement of the robot and the robot should be able to take the turn as the situation demands. Now, the task is related to the dancing movement of the robot. The robot will be able to dance by maintaining its dynamic balance. The task 4 is controlling the joints of NAO robot at different time frames.

So, at different time scale, how you can control the joints, the different joints of the NAO robot, by varying the angular velocity, acceleration, displacement. So, those things we can study and we can also measure the joints position like angular velocity, displacement, acceleration. We can also determine how much is the torque required in a particular cycle time. So, we will be we have taken the help of software just to find out how much is the joints motion then joint torques required. So, all such things we could we carried out the experiments.

Now, while carrying out all these experiments using the real robots, we will have to take a few precautions. So, I am just going to summarize that the precautions to be taken while conducting experiments with different types of robots. For example, say the first thing we will have to take some safety measures, if the situation demands so. Depending on the experiment, we will have to put safety glasses, gloves, hard hat as these experiments are conducted in a very secure lab environment in this particular course. So, not much proper care was taken, but safety measures are to be taken particularly whenever we are going to use it in the real field.

For example, in one industry or in power plants, so there these safety measures are to be taken. Now, whenever we conduct, we will have to be careful that surrounding should be free, so that the robot can move freely in that particular environment. The user should know at least one method of emergency stop for the robot and as I told that before we start running a robot, we should know at least one method of emergency stop for the robot. Software is to be tested before we are going to use it to the real robot through simulation that software is working fine and then only you connect it to the real robot. And whenever we are doing experiment using a particular robot, we will have to keep a close watch, so

that there is no jerky movement of the joint, there should not be any vibration or the noise because if it is so, if there is jerky movement vibration, there could be mechanical failure of that particular the joint.

Now, there are a few softwares just to these are known as the firmware and the manufacturer they keep on updating. So, this particular the firmware, so those are to be updated at regular interval. We will have to take the help of preventive maintenance to use this particular robot and keep it active for a long time. So, at regular interval preventive maintenance are to be conducted and operators should be trained properly to carry out this particular the different types of experiments. Now, to summarize the outcome of this particular course, the participants will be gaining a lot because they will be getting the exposure of conducting experiments, five different experiments using five different robots.

So, they will know how to control a robot besides knowing the different components, different parts of a robot, how to teach a robot that means, how to give instruction to the robot, how can you make one robot intelligent that means, how can you incorporate intelligence in the artificial way to the head of a robot to perform some pre-specified task and how to make a robot autonomous, so that it can take the decision at its own. So, these are the things which we are going which we have discussed in details and through some real experiments, we have tried our level best to give you the difference between a robot teaching that is a taught robot, intelligent robot and autonomous robot. Now, before I stop, let me once again tell you that robots are designed and developed to perform some pre-specified task. The parts are manufactured, designed manufactured, assembly is done, it is tested for their control and once it is found to be suitable that the robot can be run, we try to give some instruction through teaching, so that the robot can perform some pre-specified task. We can make the robot intelligent by incorporating intelligence in the artificial way, artificial intelligence we can incorporate and we can also make the robot autonomous, so that it has got the ability to take the decision as the situation demands.

And my final comment on this particular course like there is a difference between a taught robot, intelligent robot and autonomous robot and we tried to give emphasis on how to teach a robot, how to make a robot intelligent and how to make the robot autonomous. Now, if you want to make robot intelligent, you should be able to take the decision as the situation demands and if you have got the necessary permission to act as an intelligent way, then only the robot will become autonomous. And if it follows only the taught instruction to perform the task, it will be simply a taught robot. So, not a taught robot is not an intelligent robot. So, there is a difference between the taught robot, intelligent robot and autonomous robot.

So, I hope all the participants could gain a lot through this particular course and they have enjoyed this particular course. Thank you.