Lecture 11: Experiment 04: Navigation of Drone

I welcome you all to experiment 4 of this NPTEL course on Experimental Robotics. Experiment 4 is on Navigation of Drone. Now, this is the drone, which we are going to use for the experimental purpose and this is the remote controller for this particular drone. Now, these are the concepts covered. I will give a brief introduction to a drone, the concept of flight and walking condition or a walking principle of a drone. The various components of a drone will be described.

The aims and objectives of these experiments will be stated. Real experiments will be carried out like a few tasks will be carried out with this particular the set of experiments. Inferences drawn from the experiments will be discussed in details. Some precautions, which are to be taken to carry out these experiments will be discussed in details.

A few applications of this type of robot, that is drone will be discussed in details and some references will be given. Introduction, now to start with, let me try to define, what do you mean by a drone? Now, a drone is an unmanned aerial vehicle, that is UAV. Now, this unmanned aerial vehicle, drone, is operated without using any onboard human pilot or the operator. That means, this particular drone can be operated by a human operator remotely or this particular drone can work as an autonomous robot. So, it can take its own decision and implement.

Now, let me once again define, the drone is actually a robot, which is not controlled by an onboard human operator, but it is controlled by a human operator remotely or it can work as an autonomous robot. Now, if you see the literature, the drone has come as an outcome of two important major areas. The first one is your aerospace system, aerospace engineering and we know that aircraft works based on the principle of aerospace engineering and this is nothing, but an aerospace system. And, we have got the field of mobile robotics and this particular intersection of this aerospace and your mobile robotics is nothing, but the drone or the aerial robots or UAV. So, this is the way we can define, the drone is actually the intersection of aerospace system and mobile robotics.

Now, let us see how to control this particular drone, what are the different components, if you want to design and develop a drone and how does it work. So, all such things we are going to discuss in details and it will be verified through real experiments also. Now, let us give the introduction to the concept of flight. So, how does a drone fly? Now, to discuss the concept of flight of drones, I will have to concentrate on the principle of aerodynamics, then comes your the control, then the principle of propulsion and its navigation. Now, let me start with the concept of this aerodynamics.

This deals with the study of an air, the way it interacts with one moving object. Now, let me take a very simple example. Now, supposing that I am just going to show one moving object in air. So, what is the interaction of the air of this particular moving object? So, how

does air interact with the moving object? So, aerodynamics tries to deal with that. Now, supposing that here in this particular schematic view, let me consider that this is nothing but the body of the drone and it has got say one propeller, another propeller here.

Now, whenever it moves in a direction like this in air, this will be subjected to a lift and it will also be subjected to drag. Now, let us try to understand the meaning of this particular lift. So, this is the lift acting vertically upward and this is opposite to the direction of the gravity. So, lift is actually opposing the force of gravity. Now, this particular lift force occurs due to the difference between the upper and lower surface, the pressure difference between the upper and lower surface of the wing.

So, if I concentrate on a particular propeller or a wing and we try to find out what is the pressure on the upper surface of the wing and the lower surface of the wing and this particular difference is pressure between the upper and lower surface will create lift and lift is acting vertically upward opposite to the direction of the force of gravity. Now, there is another term that is called the drag. So, if the drone is moving along this particular direction, the drag is going to work as the resistance to motion and it is caused by air. So, the drag is going to act in this particular direction. So, this particular drone is subjected to the lift and drag and at the same time, this drone will have to maintain its stability.

So, how to maintain the stability and how can you call the drone is stable? Now, a drone will be called stable while flying, if it is not subjected to undesired roll, pitch and yaw movements. Now, let me repeat. So, whenever it is flying, if this particular drone is not subjected to some movements due to roll, pitch and yaw and this particular movement is undesired, then it is called that the drone is stable. Now, let us try to explain the meaning of this particular term that is the rolling, pitching and yawing. Now, let me consider one coordinate system like X, Y and Z.

Supposing, that this is the X coordinate, Y coordinate and this is the Z coordinate. So, by definition, rolling means it is the rotation about X, it could be either clockwise or anticlockwise. So, this is what you mean by the rolling movement. Then pitching is actually the rotation about Y. So, this is your pitching movement and the rotation about Z is nothing, but the yawing movement.

So, the rolling, pitching and yawing. So, a drone is called a stable one, whenever there is no unintended roll, pitch or yaw movements. So, this is the way we define a stable drone. Now, then let me try to concentrate on the control related to the concept of flight. Now, here these particular drones may have two possibilities, the drones may have fixed wings or the drone or the quadcopter may have some sort of the blades or the propellers or the rotors.

So, where the angle of tilt can be varied or the controlled. Now, if I consider the fixed wing drone and to explain the concept of its control. So, I will have to consider the terms like

your algorithms, elevators and rotors. Now, let us see what do you mean by that. Now, alleran actually indicates the rolling control, that is, the rotation about X.

So, if I consider that this is the alleran type of the control surface. So, this shows that, it is the rotation about X, then rotation about Y, which is nothing, but the elevators. So, this is the rotation about Y and rotation about Z that is the yaw control and that is known as the radars. So, if the drone is having some sort of your fixed wing, then we can go for this type of the control, the concept of control. On the other hand, if we can adjust the tilt of the rotor blades, then what we can do is, we can go for this type of concept like your, if you see the diagonally opposite propellers, they are having either clockwise or anticlockwise movement.

So, we can have either clockwise or anticlockwise movement. Now, in this rotor tilting that particular method of control. So, what we do is, we adjust the tilt of the rotor blades to control the movement of the drone. So, by altering the speed and tilt of this individual motor or the rotor rather, we can control the roll, pitch and yaw control of this particular drone. That means, your the rotation about X, rotation about Y, rotation about Z of this particular drone will be controlled by changing the speed and tilt of the individual rotors.

And here, you can see if I consider the throttle control, so it can move vertically upward, downward, then comes your, you can see the pitch control. So, this shows the pitch control, this shows actually the roll control and this is nothing, but the yaw control. So, once again let me repeat. So, by rolling we means the rotation about X, pitching we means the rotation about Y and yawing movement we means the rotation about Z. Now, this is the way actually we can control this particular the drone either in throttle control mode or the pitch control mode or the roll control mode or yaw control mode.

Now, here one thing has to be actually noticed which I have already mentioned. So, we consider the two vertically, sorry, the diagonally opposite your the propeller or the rotor. And if these are rotating in the clockwise, the other diagonal will be rotating in the anticlockwise. So, this is the way actually we can use the concept of the rotor tilting. Now, to summarize, the drone may have both fixed wings or fixed propeller and it can also have some sort of the rotors or the propellers, where the angle of tilt can be varied and speed can also be varied.

So, this is the way actually we can control the drone whenever it is flying. Now, let me try to give some information regarding the propulsion. So, this propulsion is the mechanism by which the drone creates some forward and upward motion. Now, to create this forward and upward motion, the drone will have to use either the electric motors and the rotors. So, by varying the speed of the electric motor, we can vary actually the altitude and direction of the drone.

We can also use some sort of the jet or propeller engines particularly for controlling or the

propulsion of a large size drone. And then, there is a concept of the thrust vectoring. Some drones can control the direction by adjusting the angle of thrust from their engines or the rotors. So, by changing the angle of thrust, once again the propulsion can be decided. Now, then comes the concept of the navigation.

So, drones rely on various systems for navigation. For example, during navigation, we take the help of some global positioning system, that is the GPS. Now, this global positioning system or GPS is going to indicate the drone's position and altitude. Similarly, we can have the inertial measurement units or the IMUs and these IMUs use accelerometer and gyroscope to measure the drone's velocity and orientation. So, to measure the change in drones velocity and orientation, we generally take the help of IMUs.

And, of course, we use computer vision with the help of camera, the drone can collect information of the surrounding and we do image analysis to find out, if there is any possible location of the obstacle and there will be obstacle avoidance scheme during this particular your the navigation of the drone. Now, then comes your the remote control. This I have already mentioned at the beginning of this particular lecture that a drone can be controlled remotely by one human operator and to control this particular drone by a human operator remotely. So, we will have to take the help of wireless communication and that means, the signal should go to the controller of the motor mounted at the drone wirelessly. At the same time, we should also collect information which are required for the purpose of controlling that particular drone remotely.

So, these are the fundamentals and now, I am just going to concentrate some time on the working principle of a particular, the drone. Now, the drone is flying in air and of course, we take the help of Newton's third law of motion, that is for each action, there is an equal and opposite reaction. So, whenever we are considering the movement of this particular drone in the upward direction say. So, definitely there will be some thrust in the downward direction and due to the reaction so, the drone is moving in the upward direction. So, there is a concept of thrust also like whenever the quadcopter push air downwards, definitely it is going to get the reaction force in the opposite direction, that is nothing, but the thrust.

Now, we also use the Bernoulli's principle, for example, say air is nothing, but a compressible fluid. So, there also we can use the Bernoulli's principle like the sum of the energy due to velocity, energy due to the pressure and energy due to the height become almost equal to constant. So, using that also, we can find out what could be the variation of pressure, velocity and all such things and that particular things help us to explain or understand the working principle of a particular the drone. Now, then there is a concept like the quadcopter will tend to rotate anti-clockwise and when the propeller rotates clockwise. So, when the propellers rotate say clockwise, the quadcopter will try to rotate anti-clockwise and this resultant rotational force is called torque.

Now, all of us we know. So, whenever there is some, whenever we are using two diagonal propellers, say clockwise and the other two anti-clockwise. So, it will generate some torque and this particular torque is going to help us for getting the relative the rotational, the motion. So, this is the way actually the drone works. Now, if you see the quadcopter has four different types of movements. It can have vertical movement, it can have some rotational movement.

Now, this rotational could be of three types, there could be the rolling movement, there could be the pitching movement, there could be yawing movement. So, this vertical the robot, this quadcopter can move against gravity or come down in a controlled manner, this is possible like we can change the position. We can also change the rotation and this particular change in rotation will be expressed in terms of the rolling movement, pitching movement and the yawing movement. Now, this particular front to back this lateral movement that could be due to the pitching and this left to right lateral movement that could be due to this particular the rolling. Now, this drone has got 6 degrees of freedom.

Now, all of us we know a 3D object in 3D space needs actually the 6 independent things to describe and it has got 6 degrees of freedom. Now, to represent the linear movement along X, Y and Z, let me consider this is X, this is your Y and this is Z. Now, if I just concentrate on the mass center of this particular the drone. So, to represent the mass center, what we need? We need the X, Y and Z coordinate and what we need? Three more things your rotation about X, rotation about Y and rotation about Z that is to represent the orientation, we need these three information. Now, this rotation about X is nothing, but the rolling then comes your the rotation about Y is nothing, but the pitching and the rotation about Z is nothing, but the yawing.

So, we need three information to represent the position and three other information to represent the orientation. Now, with this, now let me try to concentrate on the different components used, while developing a particular the drone. Now this particular picture has been taken related to the phantom 4, that particular the drone. Now, if you see this particular drone has got the propeller and the propeller will be actually moved using some motor and then, we have got the power port module here, then electronic speed controller, then comes your GPS module, then flight LED, then comes your we have got the drone camera here and in this particular view, we can see that your obstacle avoidance sensor we have got, then your downward ultrasonic sensor we have, then the drone flight controller we have. So, these are actually some of the necessary components of a particular, the drone.

Now, here I am just going to show in a more clear way like your we have got the GPS here. So, the here we can get the GPS, then the propellers this is nothing, but the propeller for the drone, below the propeller we have got the motor, then we have got the front LED, then comes your the gimbal or the camera we have got here. So, this is the camera mounting, then comes your forward vision system, then intelligent flight battery. So, we have got the intelligent flight battery here, then aircraft status indicator, then comes your rear vision

system we have, infrared sensing system we have, then comes your camera. So, we have got the camera here, then comes your micro USB port.

So, micro USB port we have here, then comes your camera micro SD card slot, there are some slots, then downward vision system we have got the downward vision system. So, these are the components of a particular the drone. This is another view that is the back of this particular the Phantom 4, you can see that the battery assembly the drone battery is here, then comes your main camera board just to carry out that processing image processing related activities, then we have got the antenna here and this shows the remote controller used for this particular controlling the drone. So, we have got the main remote controller board and there are a few joystick. So, with the help of this joystick and a few buttons, you can control the movement of that particular the drone.

Now, this shows actually the remote controller. So, you have got the antenna here, this is the display the screen, then we have got the control stick, we have got the control stick like this and this is actually the return that button used to bring to the home position. There are a few other buttons with the help of which we can control remotely that particular your the drone. Now, the different sensors we use camera we used in drones and if you see we have already discussed a little bit that this particular the drone is actually equipped with a few sensors discussed like inertial measurement unit that is the IMU sensor it has got and with the help of this IMU. So, we can find out the drones orientation and the acceleration.

Then we have got the GPS that is your global positioning system and with the help of this GPS, we can find out the drones location and altitude. Then of course, we have got barometer just to measure the air pressure, we have got the camera just to collect information of the surrounding of that particular the drone, we have got compass and this particular compass is used just to maintain the heading and the orientation. So, we have got the compass, we have got the battery sensors and this particular battery sensor is going to help us to monitor the health of that particular the battery. Now, besides that we will have a few other sensors also. For example, we have got thermal imaging sensor, LIDAR sensor, ultrasonic sensor, then stereo-vision sensor, infrared sensor.

So, we have got a large number of sensors mounted on that particular the drone. Now, these sensors are used for different purposes. For example, we can find out the distance, we can find out if there is any possible location of the obstacle, we can find out the age of a particular obstacle and how to find out the collision free path during navigation that you can find out. We can also use different types of sensor just to find out what is the internal condition of that particular the drone and those sensor are known as the internal sensor. So, drone is mounted with a few internal sensors and a few external sensors.

So, these are the sensors we generally use in a drone, so that we can collect information of that particular the surrounding and its internal condition. Now, in this particular the experiment, we are going to perform a few tasks and those tasks are related to the

waypoint navigation, then comes your the trajectory navigation and autonomous flight. So, these aims and objectives, we are going to discuss in more details, wherever we are going to discuss a few tasks, which we are going to carry out with the help of the real robots that is your the drone. Now, in the field experiment, the five tasks will be carried out. The task 1, that is the maneuvering of this particular drone from one starting point to another goal point through some intermediate points.

Now, this particular task will be performed through the manual piloting as well as we will be using that auto piloting that particular system. Then, task 2, the drone is going to follow some the straight path. So, that particular experiment will be shown in task 2. Then, task 3 deals with the circular path following. So, there will be one circular path, which will be defined and the drone is going to follow that particular the circular path.

The task 4 is related to tracking and tracing of one human being. So, one human being will be tracked and traced and this drone is going to follow that particular the human being. Then, task 5, some actually the trajectory or the path will be drawn on the remote controller and drone is going to follow that particular the path or the trajectory, as accurately as possible. Thank you.