Mechatronics
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Lecture - 39
ABU Robocon 2019 – Part-II

I welcome you all to today's lecture on Mechatronics. In this lecture, we are going to talk about ABU Robocon 2019, the II part. In the I part, I have discussed the problem statement as well as the IIT Roorkee team strategy for the manual robot, and today, I am going to talk about their strategy, design, task performance for the autonomous-legged robot.

I would like to acknowledge the team Robocon, IIT Roorkee 2018-19, and I am thankful to Bhavya Giri Goswami, the team leader who provided the discussed documentation, which I am going to present.

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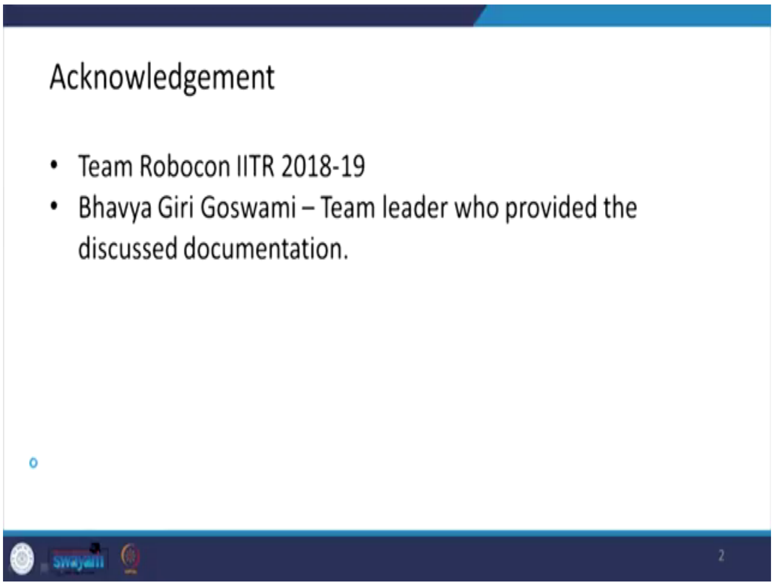

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The problem statement I before we start, I would just like to give you a brief. So, these few slides will be repeated for the previous lecture in order to maintain continuity. The problem statement was designed by Mongolia for 2019 Robocon and whose theme was based on sharing knowledge. It is related to Urtuu, a system of Mongolian tradition. The two robots called Messenger Robot have to be made MR1, which is manual or semi-automatic, and MR2, which is fully automatic.

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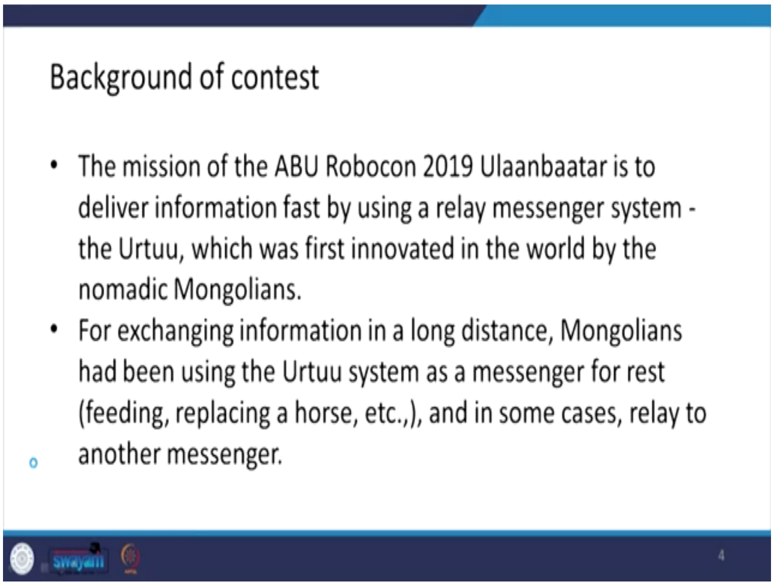

If we look out at the background of the contest, the mission of ABU Robocon 2019 Ulaanbaatar is to deliver information fast by using a relay messenger system, which they call Urtuu, which was first innovated in the world by nomadic Mongolians. For exchanging information in a long-distance, the Mongolian has been using the Urtuu system as a messenger for rest that is feeding, replacing horse etcetera and in some cases relay to another messenger.

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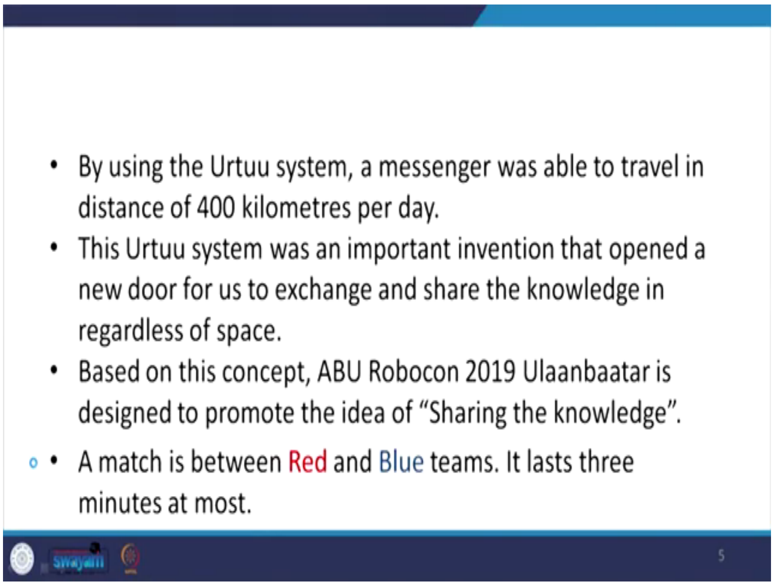

By using the Urtuu system, a messenger was able to travel a distance of 400 kilometers per day. This Urtuu system was an important invention that opened a new door for us to exchange and share knowledge regardless of the space. And based on this concept, ABU Robocon 2019 Ulaanbaatar is designed to promote the idea of "sharing the knowledge." A match is between the red and blue teams, and it lasts three minutes at most.

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This is how the game area is. You have Khangai urtuu, and this is Shangai area, this is line 1, you have line 2, you have line 3. You have Gobi urtuu. This is there in the Gobi area, and then you have the Mountain urtuu, Mountain area, and Uukhai zone is here. This is the throwing zone, and this is the landing zone over here, and we have seen in the previous lecture how the manual or semi-automatic board covers the forest area and the bridges.

For the autonomous board, the area which is to be covered in this one, Sand dune, Tussock, and the Mountain. So, Tussock and Sand dune is the obstacle over here which the 4-legged robot is supposed to travel and then, it has to climb the mountain area and then, it has to reach to the Uukhai zone.

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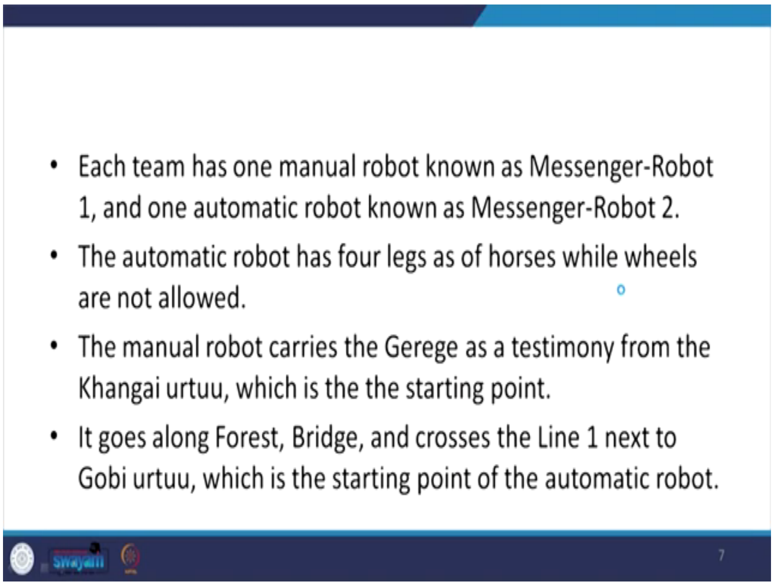

Each team has one manual robot known as Messenger- Robot 1 and one automatic robot known as Messenger- Robot 2. The automatic robot has four legs like horses, while wheels are not allowed. The manual robot carries the gerege as a testimony from the Khangai urtuu, which is the starting point. It goes along the forest bridges and crosses line 1 next to the Gobi urtuu, which is the starting point of the automatic robot. After Messenger Robot 1 reaches the Gobi urtuu, Messenger Robot 1 passes the gerege to Messenger Robot 2 at Gobi urtuu, and once Messenger Robot 2 successfully receives the gerege, it can go along the Gobi area. Messenger Robot 2 must go by four legs like a horse.

The problem statement has the constraint that one cannot use the wheels for it, and the Messenger Robot 2 has to pass through Sand dunes and the Tussock and direct to the Mountain urtuu.

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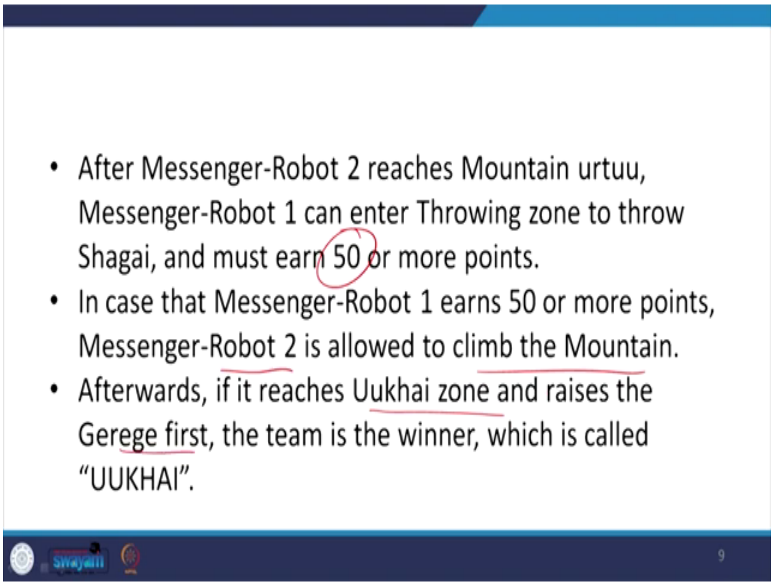

After Messenger Robot 2 reaches the Mountain urtuu, Messenger Robot 1 can enter the throwing zone to throw the Shagai and must earn 50 or more points. In case Messenger Robot 1 earns 50 or more points, Messenger Robot 2 is allowed to climb the mountain, and after it reaches the Uukhai zone and raises the gerege first, the team is the winner and the which is called the" UUKHAI." So, this was the problem statement.

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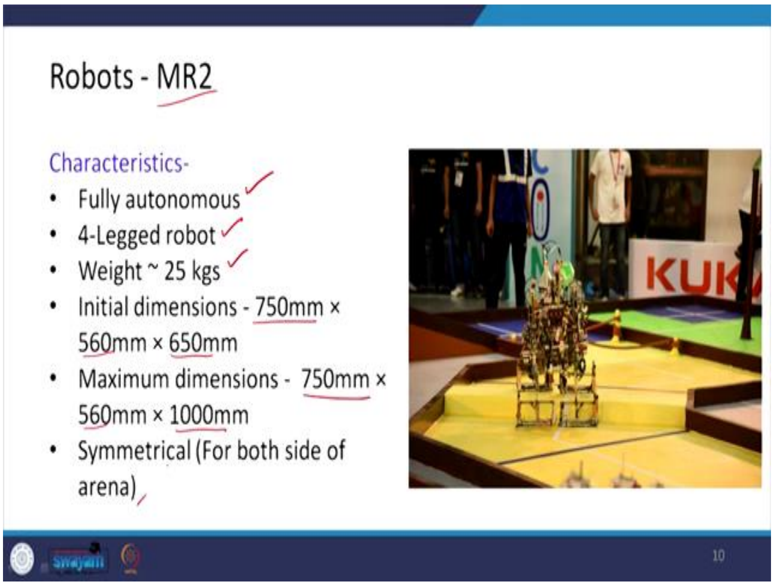

In the last lecture, I have talked about the Messenger Robot 1. In this lecture, I am going to focus on the technology development for the Messenger Robot 2. As we can see, these robots are a very good example of the mechatronic system. You have the integrator, integration of the actuators, you have integration of the sensors, you have the microcontroller controlling them, and you have a lot of programming involved in order to get the desired task.

The characteristic of this 4-legged robot is that it has to be fully autonomous, it needs to have four legs, its weight should be around 25 kgs, initial dimension is 750 mm × 560 mm × 650 mm, the maximum dimension is this 750 mm ×560 mm × 1000 mm, and it is symmetrical for both sides of the arena.

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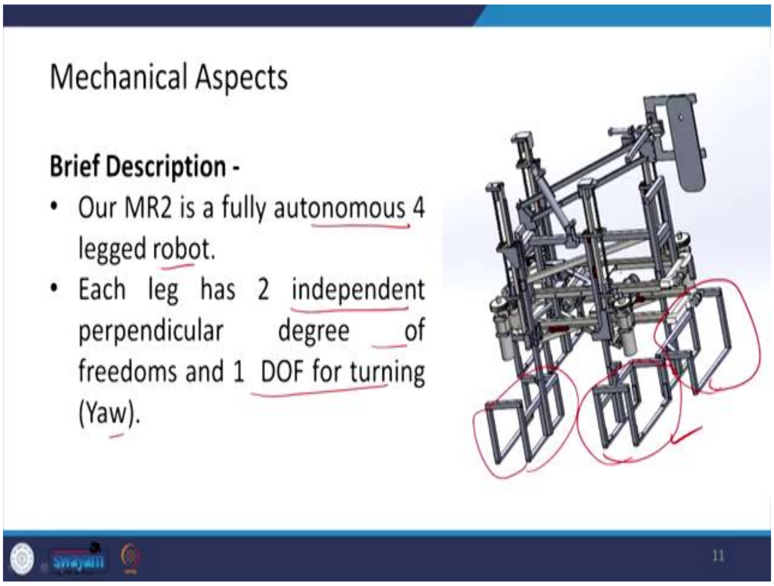

The mechanical aspect is a brief description of the robot developed by the IIT Roorkee team is that it is a fully autonomous 4-legged robot, and each leg has two independent perpendicular degrees of freedom and 1 degree of freedom for turning that is for the yaw motion, and this is the solid model of the robot which has been developed and here are the four legs so, this is 1, this is another one 2, this is three and the fourth one you have there in the background, in the backside.

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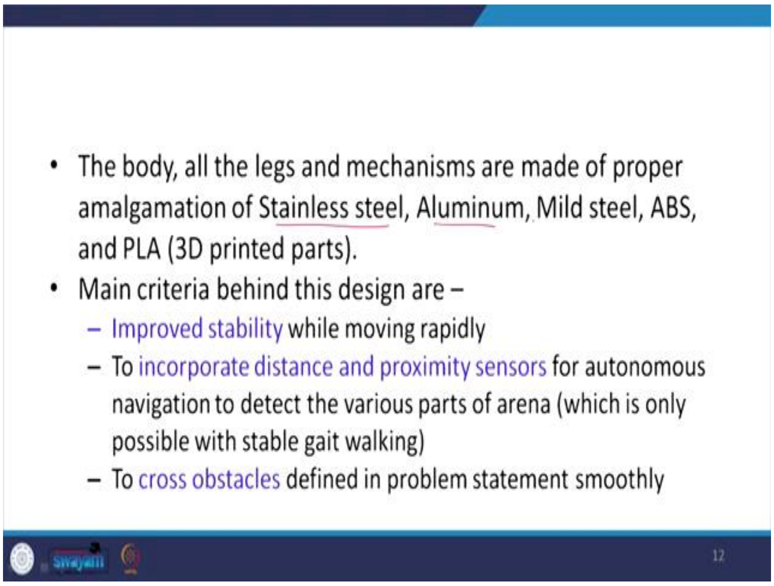

The body, all the legs, and the mechanism are made of a proper amalgamation of stainless steel, aluminum, mild steel, ABS, and PLA that is the 3D printed part. The main criteria behind this design are the improved stability while moving rapidly, to incorporate distance and proximity sensors for autonomous navigation to detect the various parts of the arena, which is only possible with stable gait walking and to cross obstacles defined in the problem statement smoothly. So, based on these criteria, the parts were designed.

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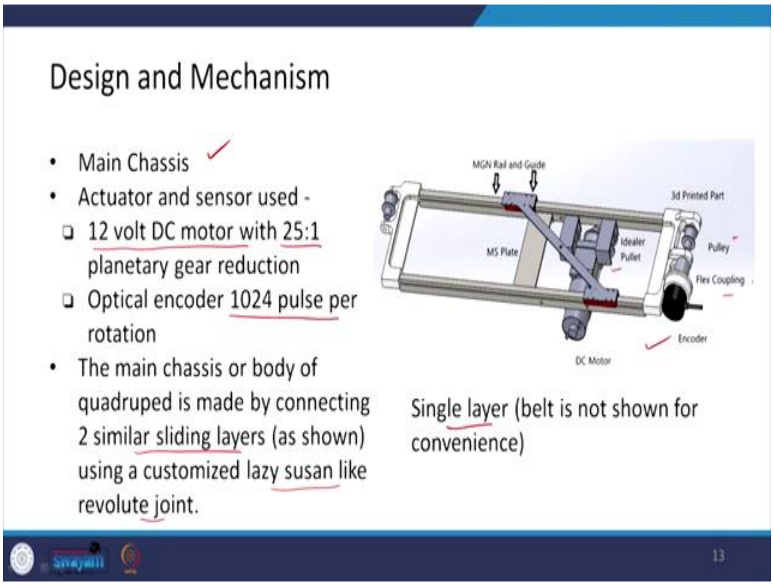

Let us look at the design and the mechanism. First is the main chassis. The actuators and sensors used here are 12-volt DC motors with 25:1 planetary gear reduction: Optical encoder with 1024 pulses per rotation. The main chassis or the body of the quadruped is made by connecting the two similar sliding layers as shown over here using a customized lazy susan like the revolute joint. This is the single layer where you can see by you have the idler pulley, pulleys are there, flex coupling is there, the encoder is there, and this is MGN rail and the guide provided over here.

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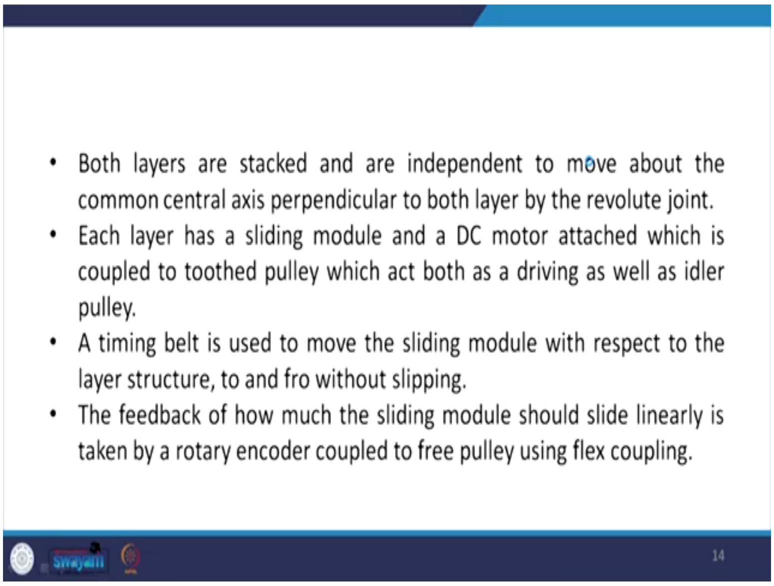

Both layers are stacked and are independent to move about the common central axis perpendicular to both layers by the revolute joint. Each layer has a sliding module and a DC motor attached with a coupled to toothed pulleys, which act both as driving as well as idler pulley. A timing belt is used to move the sliding module with respect to the layer structure, to and fro without slipping, and the feedback of how much the sliding module should slide linearly is taken by a rotary encoder coupled to the free pulley using the flex coupling.

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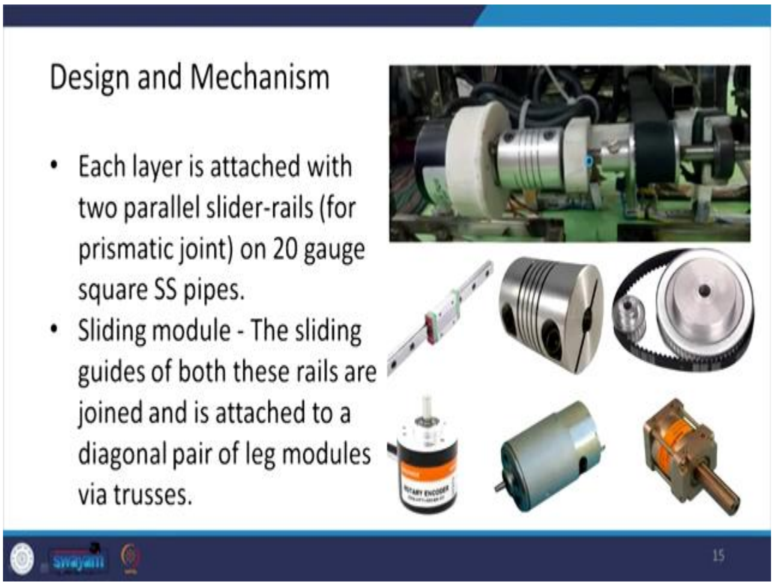

Then, each layer is attached with two parallel slide rails, as I said for prismatic joint on a 20-gauge square stainless steel plate.

The sliding guides of both these rails are joined and are attached to diagonal pair of leg modules via trusses. These are the various parts that I have been using, and you can see the sliding module over here, you have the rotary encoder, you have the actuator, you have the pulleys so, all these things are there.

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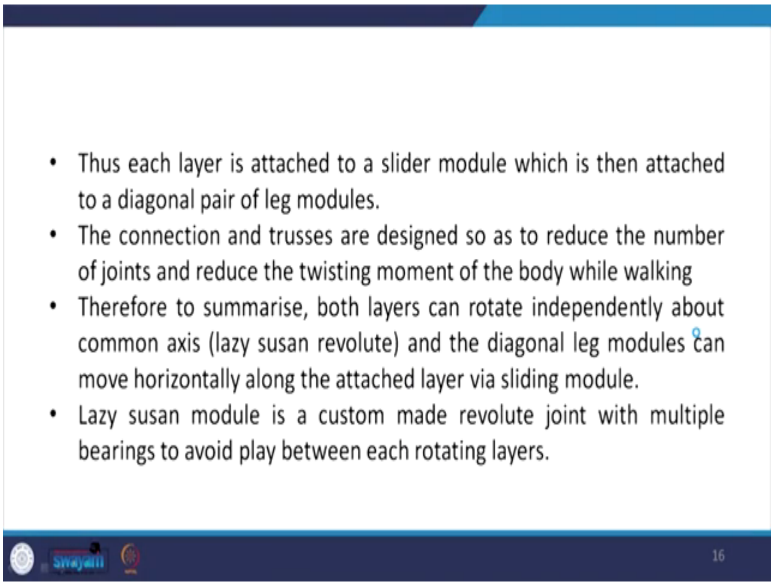

Thus, each layer is attached to a slider module which is then attached to a diagonal pair of leg modules. The connection and trusses are designed so as to reduce the number of joints and reduce the twisting movement of the body while walking. Therefore, to summarize, both layers can rotate independently about the common axis, and the diagonal leg module can move horizontally along the attached layer via the sliding module. Lazy susan module is a custom-made revolute joint with multiple bearings to avoid play between each rotating layer.

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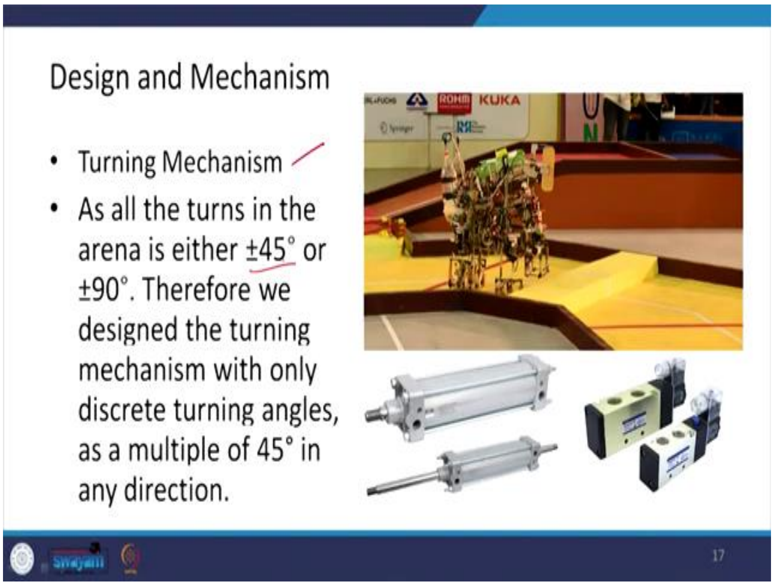

Then there is a turning mechanism for the robot to turn. So, all the turns in the arena are either $\pm 45^0$ or $\pm 90^0$. Therefore, the IIT Roorkee team designed the turning mechanism with only discrete turning angles as a multiple of 45^0 in any direction.

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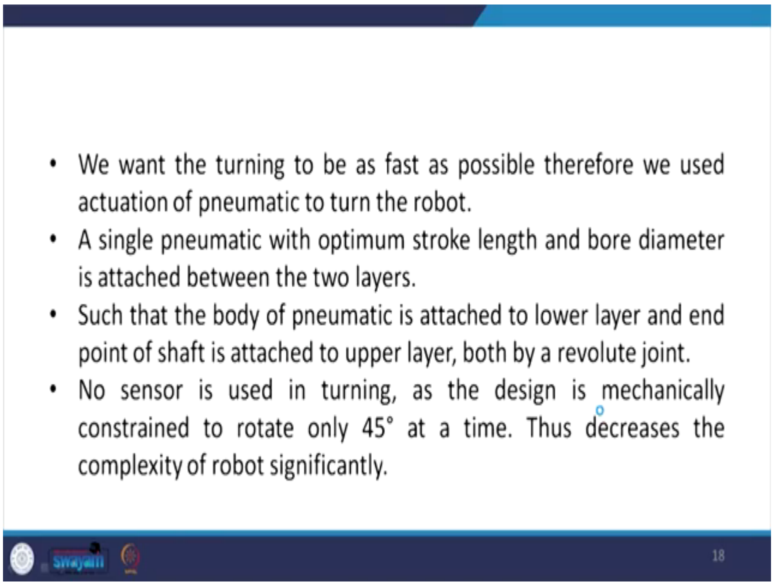

For that purpose, they used the pneumatic cylinders over here, and the turning was designed to be as fast as possible. So, therefore, they used the actuation of pneumatics to turn the robot and as a single pneumatic with optimum stroke length and bore diameter is attached between the two layers. Such that the body of pneumatic is attached to the lower layer and endpoint of the shaft is attached to the upper layer, both by a revolute joint. No sensor is used in turning as the design is mechanically constrained to rotate only 45^0 at a time. Thus, it decreases the complexity of the robot significantly.

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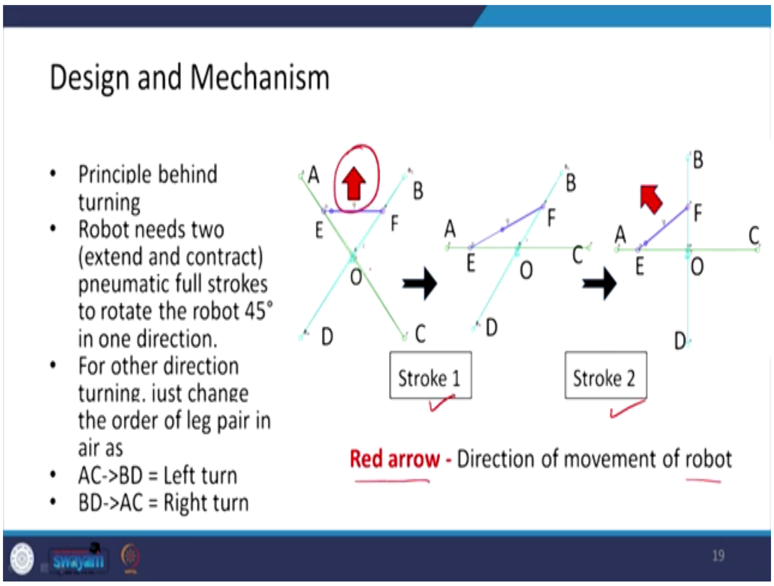

So, here the principle behind turning is that the robot needs two extend and contract full pneumatic strokes to rotate the robot 45^0 in one direction and for the other turning, the for the other direction turning, just change the order of the leg pair.

Here let us look at stroke 1, and then we will be looking at stroke 2. Here, the red arrow shows the direction of the movement of the robot. So, you can see initially that the robot is moving in this particular direction.

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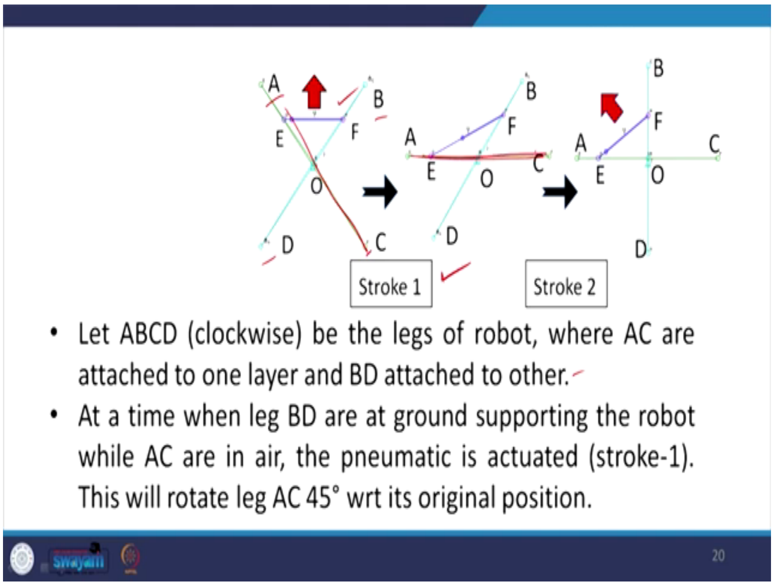

Here, ABCD is the leg of the robot, and where AC you can see is attached to the one layer and BD is attached to the other layer. Now, at a time when the leg BD is at the ground supporting the robot while AC is on the air, the pneumatic is attached, pneumatic has actuated the stroke 1, and this will rotate the leg AC by 45^0, as you can see over here, which is like this and with this one actuation, this will be turning by 45^0 as over here.

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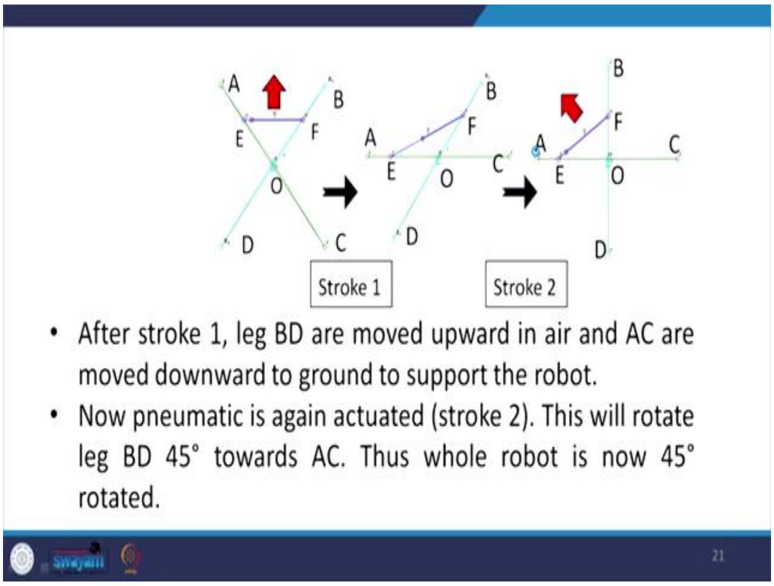

And for the next 45^0What is done is that after leg 1, after stroke 1, leg BD is moved upwards; leg BD is moved upward in the air so, this BD is moved upward in the air, and AC is moved down to the ground to support the robot. So, this AC is moved downwards in the ground to support the robot. Now, pneumatic is again actuated that is stroke 2 over here, and this will rotate the leg BD by 45 degree over here. So, as you can see, this is rotated by BD 45^0, and thus, the whole robot turns by 45^0. So, this is how the turning is achieved.

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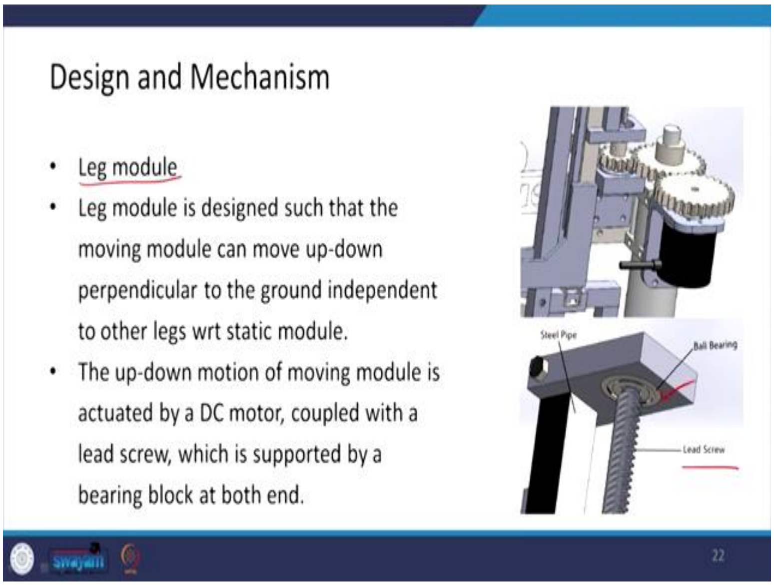

Then, coming to the design and mechanism, we have the leg module. This leg module is designed such that the moving module can move up-down perpendicular to the ground independent of the other leg with respect to the static module. The up-down motion of the moving module is actuated by a DC motor, coupled with a lead screw, which is supported by a bearing block at both end. So, you can see over the lead screw, and here is the ball bearing so, which is supporting it here, here we have the steel pipe.

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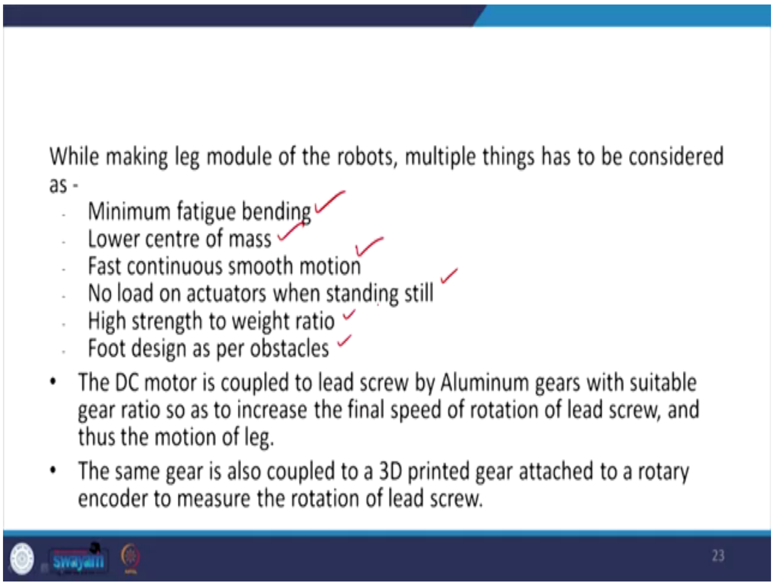

While making the leg module of the robot, multiple things have been considered, and these are the minimum fatigue bending, lower center of mass for stability, fast continuous smooth motion for the greater speed so that the task could be completed within the stipulated time of the minimum of 3 minutes, then no load on actuators when standing still, high strength to weight ratio and foot design as per the obstacle. The DC motor is coupled to the lead screw by aluminum gears with a suitable gear ratio so as to increase the final speed of rotation of the lead screw and thus the motion of the leg. The same gear is also coupled to a 3D printed gear attached to a rotary encoder to measure the rotation of the lead screw.

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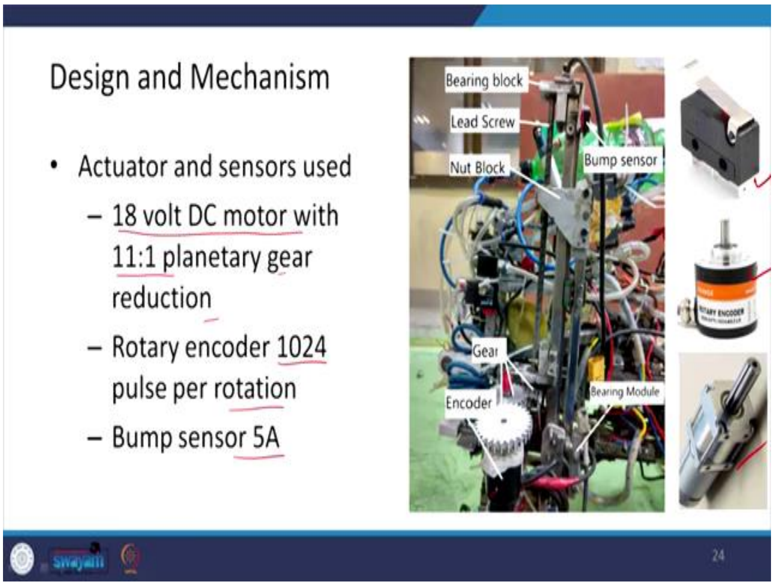

Actuators and sensors used are you can see the 18-volt DC motor with 11:1 planetary gear reduction. Rotary encoder 1024 pulse per rotation and bump sensor. So, here you can see this is the bump sensor, rotary encoder, and this is motor with the planetary gear reduction.

So, you can see here, and we have the bearing module, these are the this is the encoder gear, here is the bump sensor, then you have the bearing block, lead screw, nut block, and so on.

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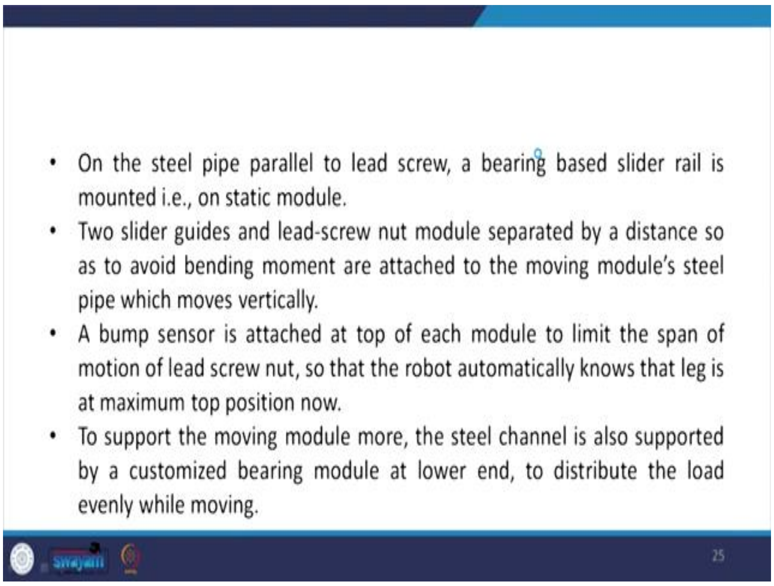

On the steel pipe parallel to the lead screw, a bearing-based slider rail is mounted that is on the static module. The two slider guides and lead screw nut module separated by a distance so as to avoid bending moment are attached to the moving module's steel pipe, which moves vertically. A bump sensor is attached at the top of each module to limit the span of the motion of the lead screw nut so that the robot automatically knows that leg is at the maximum top position now. To support the moving module more, the steel channel is also supported by a customized bearing module at the lower end to distribute the load evenly while moving.

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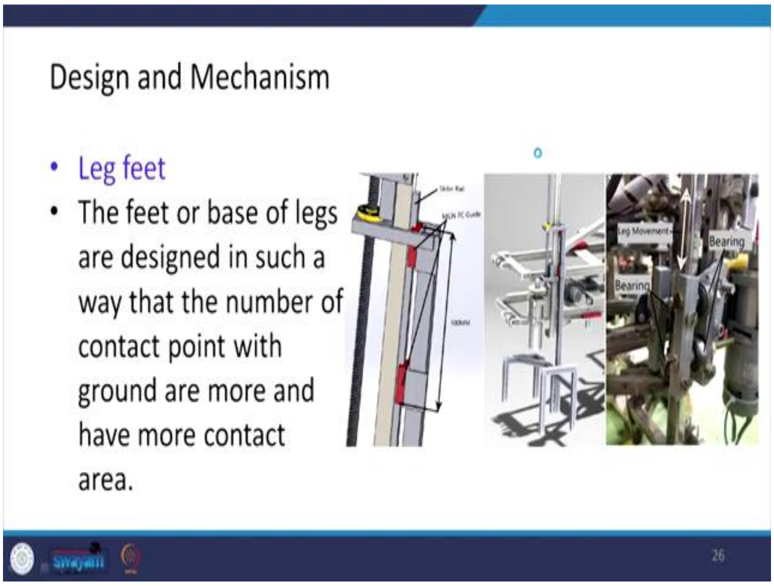

Leg feet, if we look at the feet or the base of the legs, are designed in such a way that the number of contact points with the ground is more and have more contact area so that the stability of the bot is maintained.

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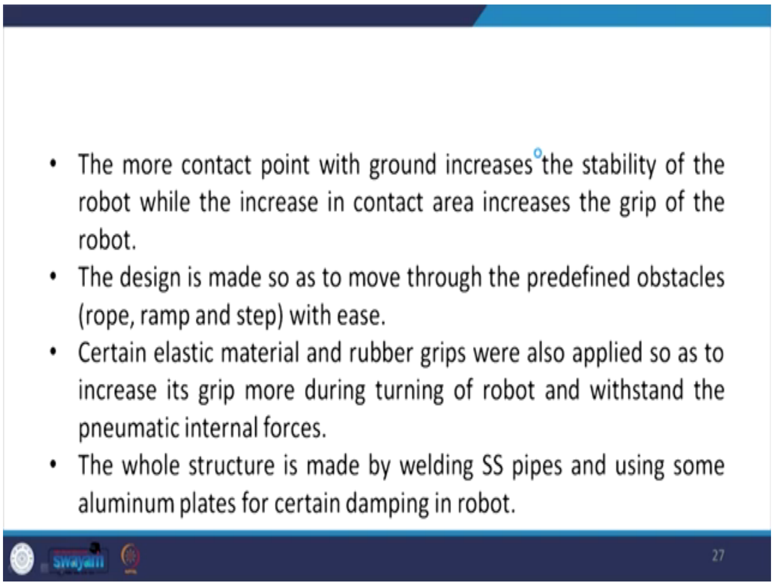

More contact points with the ground increase the stability of the robot, while the increase in the contact area increases the grip of the robot. The design is made so as to move through the predefined obstacles such as rope ramp as well as step with ease. Certain elastic material and rubber grips were also applied so as to increase the grip more during the turning of the robot and withstand the internal pneumatic forces. The whole structure is made by welding the stainless-steel pipe and using some aluminum plates for certain damping in the robot.

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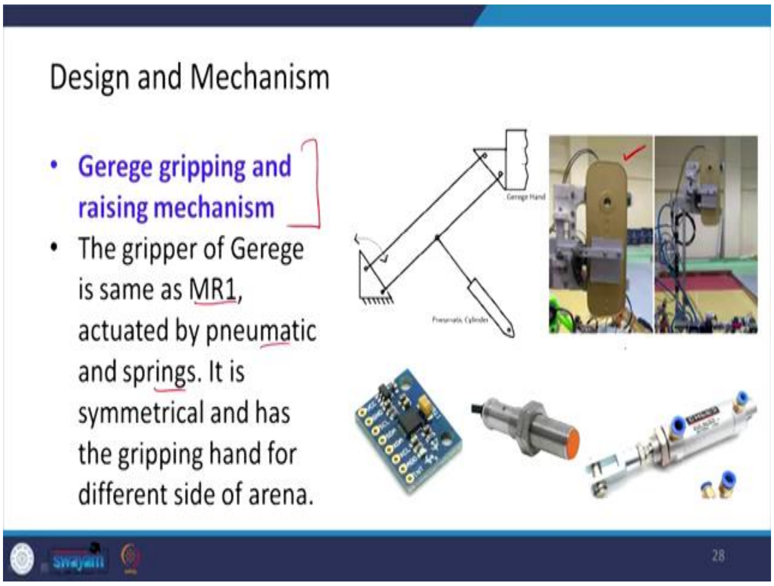

Now, let us look at the Gerege gripping and the raising mechanism. The gripper of the gerege is the same as the Messenger Robot 1, actuated by pneumatic and the spring. It is symmetrical and has the gripping hand for a different side of the arena. So, this is how you can see that this gerege has been gripped over here.

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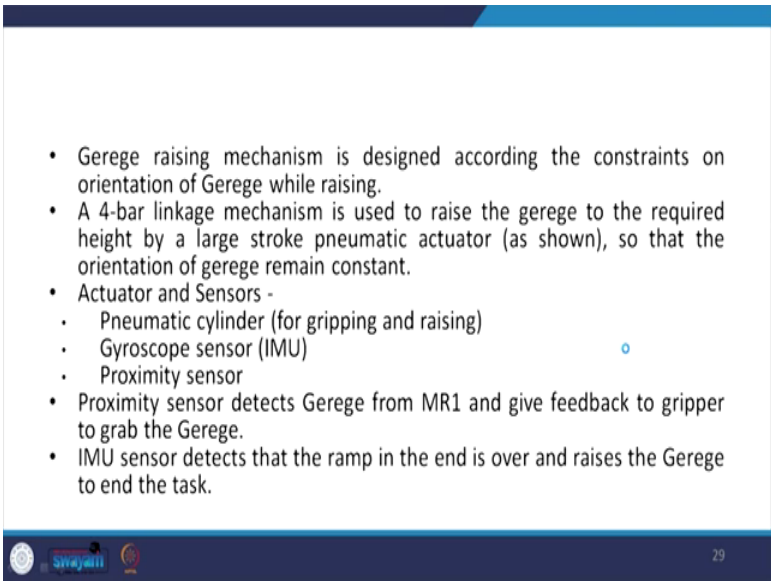

The Gerege raising mechanism is designed according to the constraints on the orientation of the gerege while raising. A 4-bar linkage mechanism is used to raise the gerege to the required height by a large stroke pneumatic actuator so that the orientation of the gerege remains constant. Actuator and sensors which are used in this one the Pneumatic cylinder for gripping and raising, Gyroscope sensor is there, and a Proximity sensor is there. The proximity sensor detects Gerege from MR1 and gives feedback to the gripper to grab the gerege. IMU sensor detects that the ramp, in the end, is over and raises the gerege to end the task.

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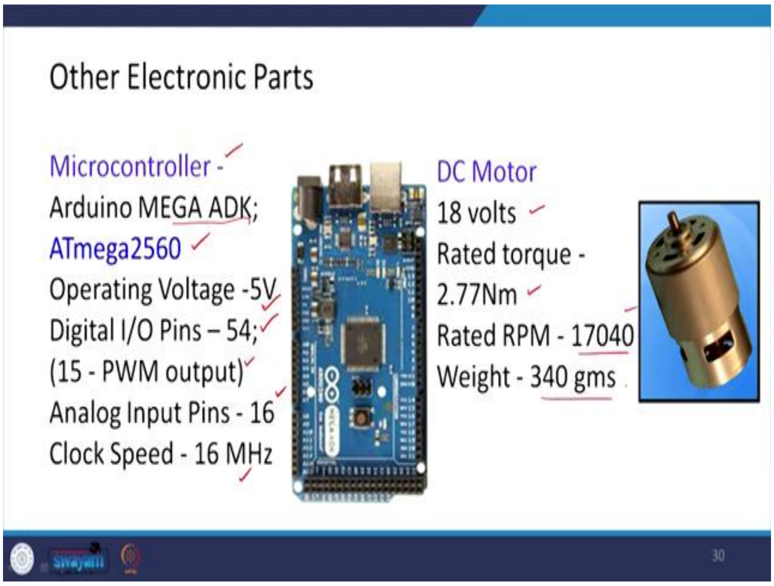

Other electronics parts used the microcontroller, Arduino MEGA ADK and ATmega2560 were used, and they have the operating voltage 5-volt, digital input-output pins 54, 15 PWM output is there, analog input pins are 16, and the clock speed is 16 MHz. Then, the DC motor is 18-volt, rated torque 2.77 Nm, rated RPM 17040, and weight approximately 340 grams.

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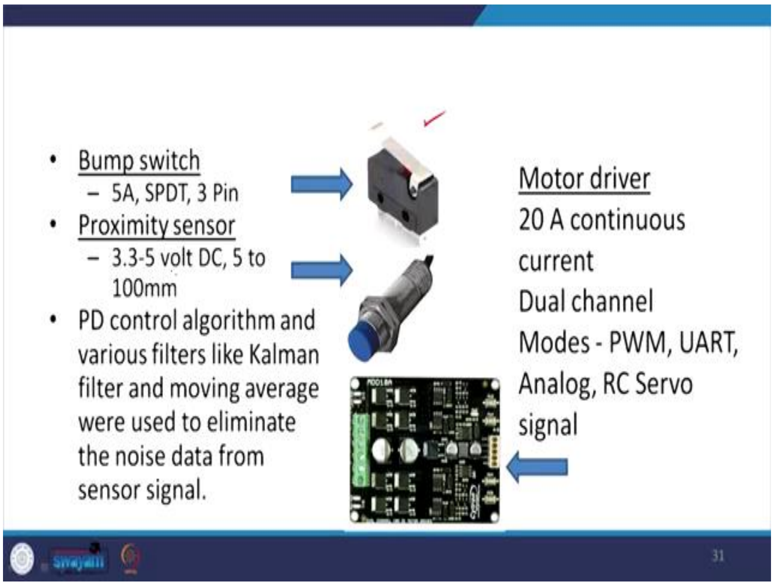

Then, the bump switch 5 ampere, single pole double throw, 3 pins. Proximity sensor, the 3.3 to 5-volt DC, 5 to 100 mm. Then, the motor driver 20 ampere continuous current dualchannel mode PWM, UART, analog, RC Servo signal they take and the PD control algorithm along with various filters like Kalman filter and moving average were used to eliminate the noise data from the sensor signal.

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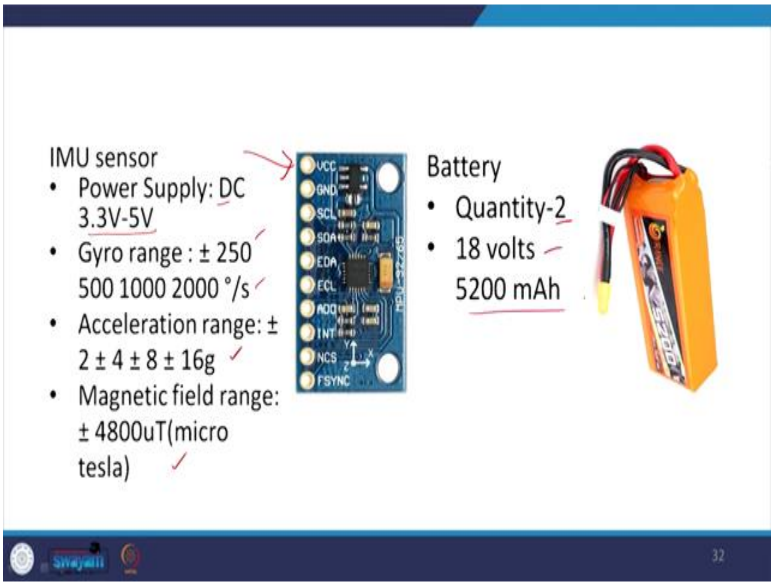

The IMU sensor which has been used is shown over here. These are the ratings for that power supply DC 3.3-volt to 5-volt, Gyro range plus ±250 these are available so many degrees per second, acceleration ranges these are available, magnetic field range this much is available and the battery used, there was 2 number of such batteries of 18-volt and 5200 mAh current capacity.

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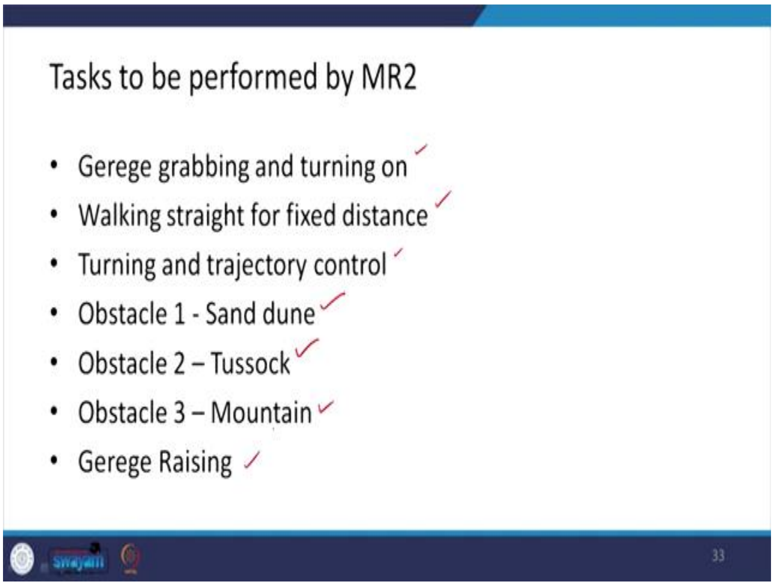

After seeing the constructional feature of the Messenger Robot 2, now let us look at the various task which these robots. This robot was supposed to do. So, the first and foremost task was that the gerege was grabbing and turning on. This gerege has to be taken from the Messenger Robot 1, then walking straight for the fixed distance it has to walk, then the turning has to be there, the trajectory control has to be there, and the three obstacles which were provided in the path of the Messenger Robot 2 these were the Sand dune and Tussock and the Mountain and then the final, Gerege raising.

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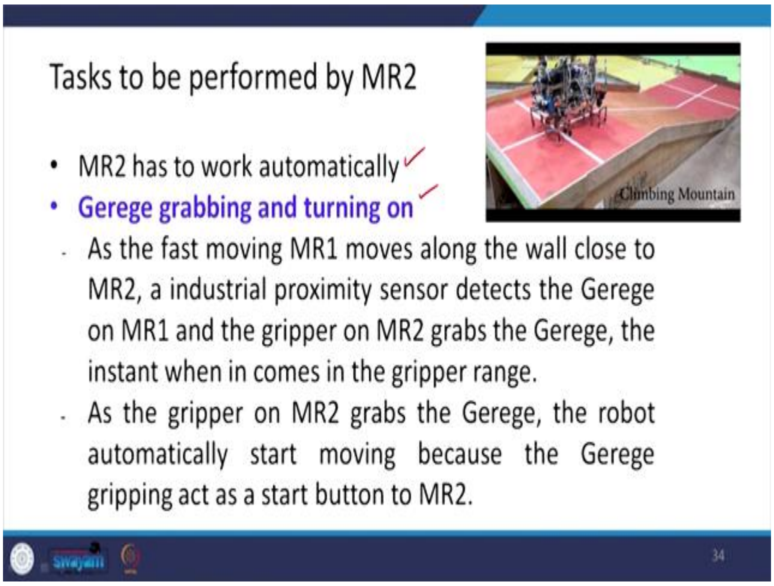

Now let us look at these tasks to be performed by Messenger Robot 2. The Messenger Robots has to work autonomously, as I have been talking to you. So, the gerege was grabbing and turning on. As the fast-moving Messenger Robot 1 moves along the wall close to MR2. An industry proximity sensor detects the Gerege on Messenger Robot 1, and the gripper on the MR2 grabs the gerege, the instant when it comes to the gripper range. Now, as the gripper on the MR2 grabs the gerege, the robot automatically starts moving because the Gerege gripping acts as a start button for the Messenger Robot 2.

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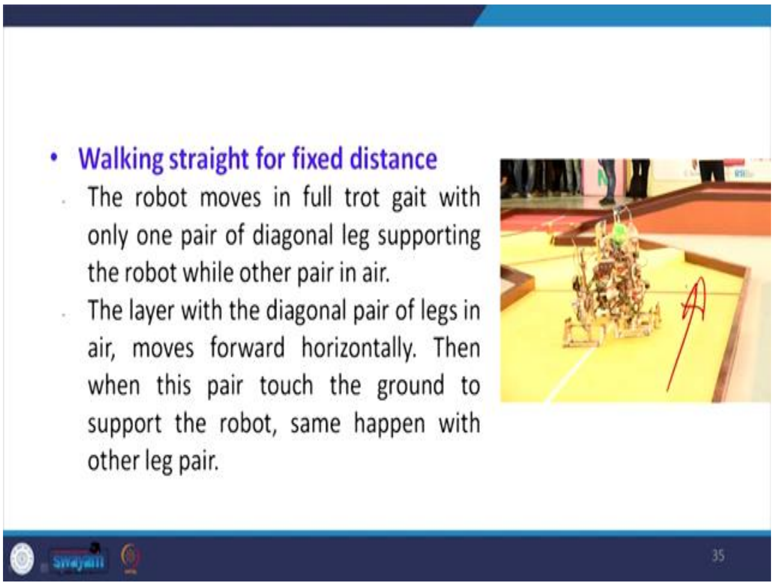

Now, walking straight for the fixed distance: It walks straight for the fixed distance, the robot moves in full trot gait, and you see the trot gait means that the diagonal legs one set up the diagonal legs are to be there in the air whereas, the other set of the diagonal legs have to be supporting the bot on the ground. With only one pair of diagonal legs supporting the robot while the other pair is in the air. The layer with the diagonal pair of legs in their moves to a forward horizontally. When this pair touches the ground, the supporting ground supports the robot. The same happens with the other pair of legs.

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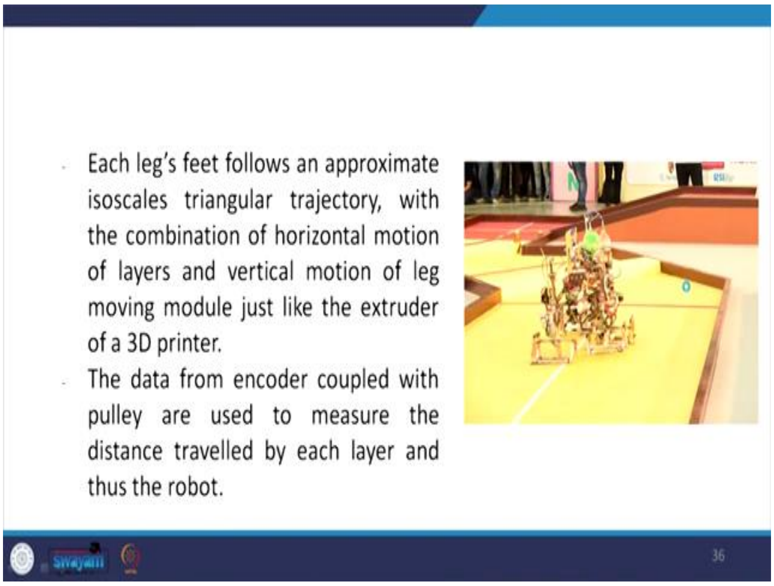

Now, each leg's feet follow an approximate isosceles triangular trajectory with the combination of horizontal motion of the layer and a vertical motion of the leg moving module, just like the extruder of a 3D printer. Now, the data from the encoder coupled with the pulley are used to measure the distance traveled by each layer and thus the robot.

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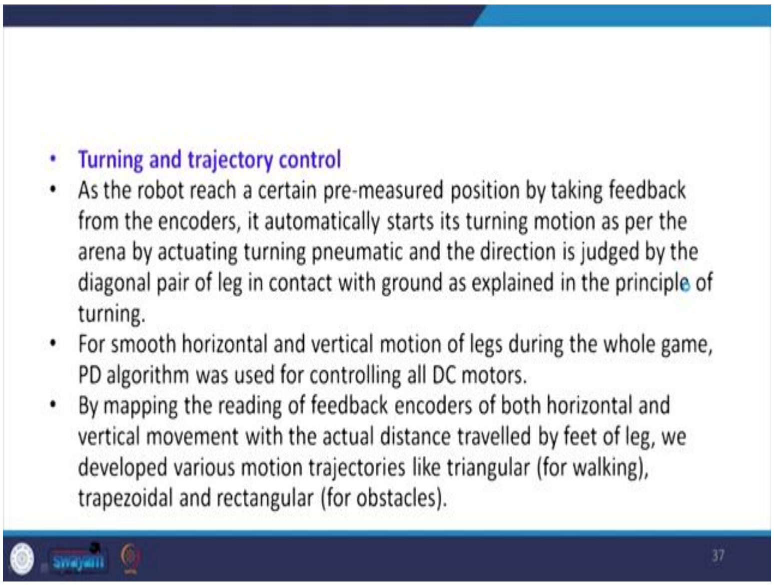

Then the turning and the trajectory control. As the robot reaches a certain pre-measured position by taking feedback from the encoder, it automatically starts its turning motion as per the arena by actuating the turning pneumatic and direction is just by the diagonal pair of legs in contact with the ground as explained in the principle of turning. Now, for smooth horizontal and vertical motion of the leg during the whole game, the PD algorithm was used for controlling all DC motors. By mapping the reading of the feedback encoders of both horizontal and vertical movement with the actual distance traveled by the feet of the leg, the Roorkee team developed various motion trajectories like triangular for walking, trapezoidal, and rectangular for obstacle and these trajectories were there for the vertical plain motion.

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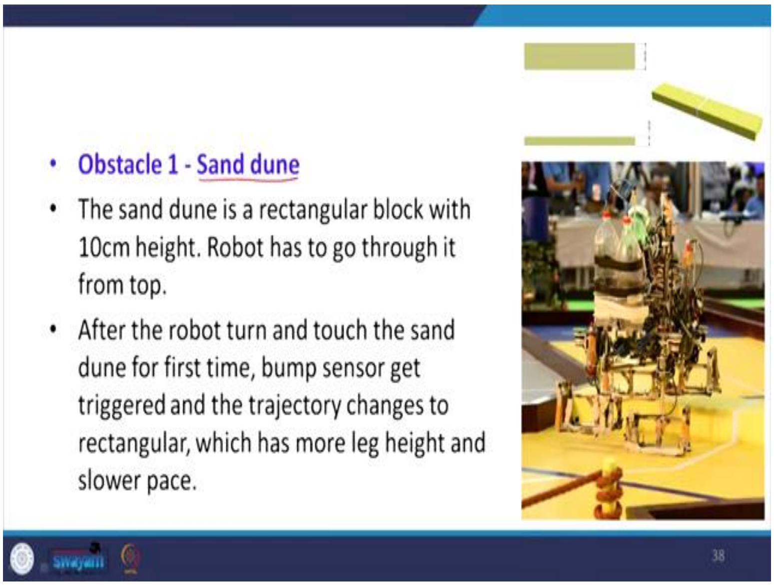

Then, let us look at obstacle 1, which is the Sand dune. The sand dune is a rectangular block, as you can see of this shape with a 100-millimeter height or 10-centimeter height. A robot has to go through it from the top. After the robot turns and touches the sand dune for the first time, the bump sensor gets triggered, and the trajectory changes to rectangular, which has more leg height and a slower pace. Now by this trajectory, a robot can move through sand dune smoothly and with stability. By getting continuous feedback from the bump sensor on each leg at different heights, the robot moves slowly through the tusk until all its legs come back to the ground at the initial height after the robot moves fixed straight distance taking feedback from the encoder and again turns 45^0 for the next huddle.

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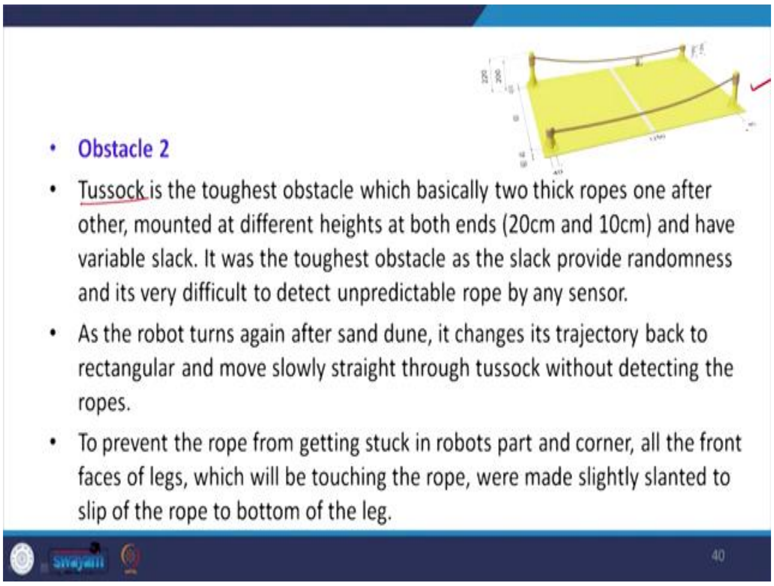

Now, let us look at obstacle 2, the Tussock. As you can see over here, the drawing for this is the perspective projection of the 3D model for this. The Tussock is the toughest obstacle two, which is composed of two thick ropes, one after the other, mounted at different heights at both ends and have variable slack. It was the toughest obstacle as the slack provides randomness, and it is very difficult to detect unpredictable rope by any sensor. Now, as the robot turns again after the sand dune, it changes its trajectory back to the rectangular and moves slowly straight through the Tussock without detecting the rope. To prevent the rope from getting stuck in the robot part and corners, all the front faces of the leg which will be touching the rope were made slightly slanted to slip the rope to the bottom of each leg.

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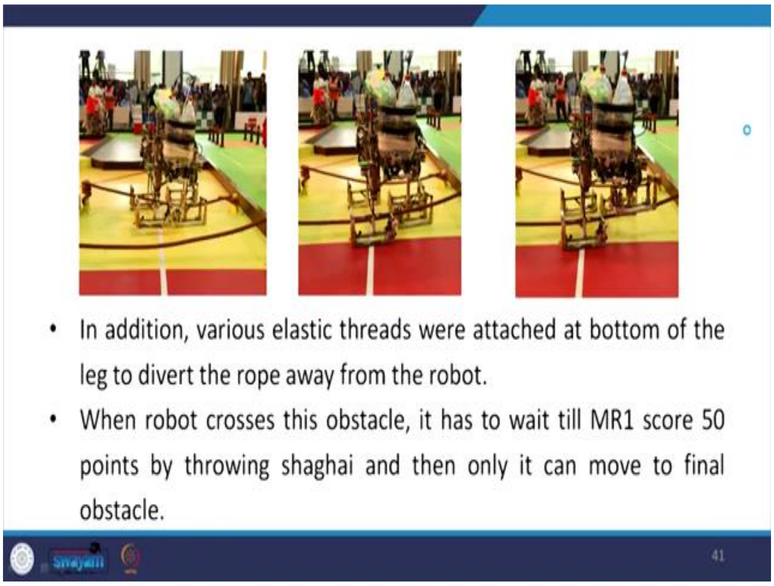

In addition, various elastic threads were attached at the bottom of the leg to divert the rope away from the robot. Now, when the robot crosses this obstacle, it has to wait till the MR1, that is, the Messenger Robot 1, scores 50 points by throwing the shaghai, and then only it can move to the final obstacle. So, this is a figure you can see the various legs that is the legs of the bot crossing the Tussock.

These pictures are from the actual arena.

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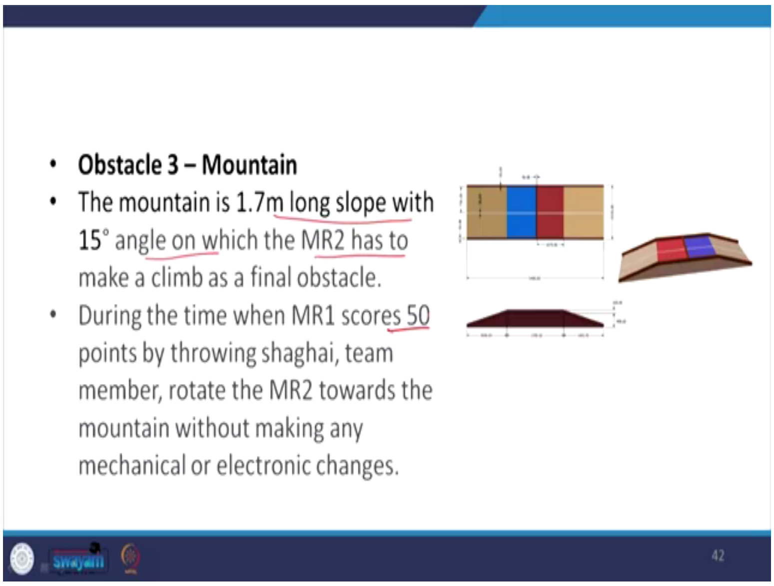

Now, let us look at the last obstacle that is not an obstacle rather a different type of terrine that is the mountain. The mountain is a 1.7-meter-long slope with a 15^0 angle on which the Messenger Robot has to make a climb as a final obstacle. During the time when Messenger Robot 1 scores 50 points by throwing shaghai, team members, rotate the MR2 towards the mountain without making any mechanical or electronic changes.

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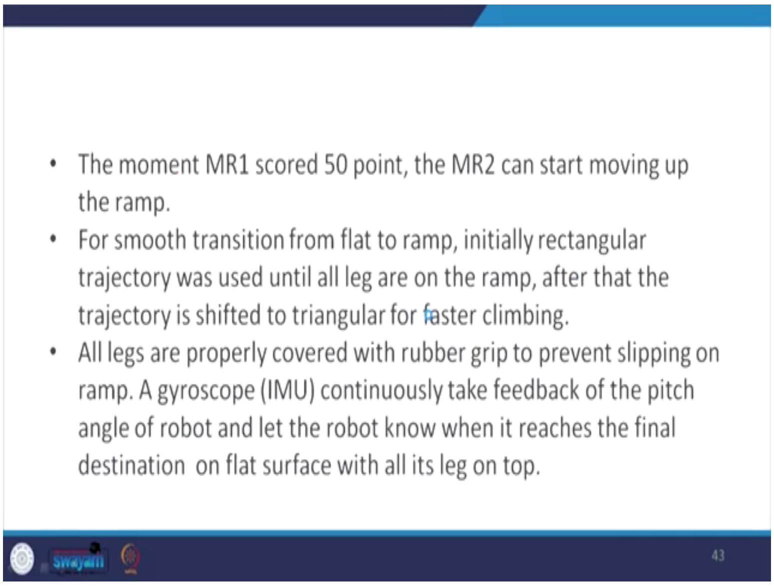

The moment MR1 scored 50 points, the MR2 can start moving up the ramp. For a smooth transition from flat to the ramp, an initial rectangular trajectory was used until all legs were on the ramps. After that, the trajectory is shifted to triangular for faster climbing. All legs are properly covered with a rubber grip to prevent slipping on the ramp. A gyroscope that is IME, continuously takes feedback of the pitch angle of the robot and lets the robot know when it reaches the final destination on the flat surface with all its leg on the top.

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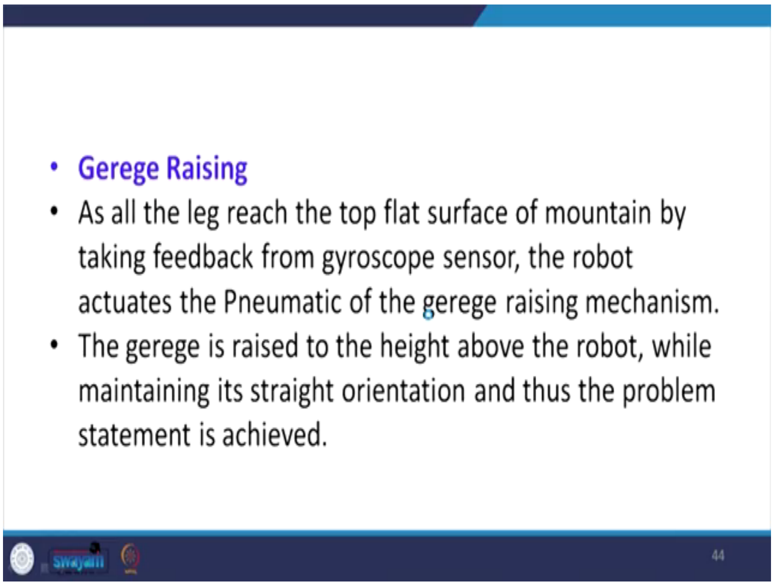

Next, the last operation is the Gerege raising. As all the legs reach the flat top surface of the mountain by taking feedback from the gyroscope sensor, the robot actuates the pneumatic of the gerege raising mechanism. The gerege is raised to the height above the robot while maintaining its straight orientation, and thus the problem statement is achieved.

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These are the members of the team Robocon IITR 2018 and 2019, and this is the trophy which they were awarded that is the Judges Special Award winner, and they were the Quarterfinalist Award winner.

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I again like to thank Professor Shailesh Ganpule, the faculty adviser for the Robocon team, and the various members from the 3rd year, 4th year, and the 2nd year all the members of the Robocon team who contributed to this very nice, useful, and learning activity.

Thank you.