Sensors and Actuators
Department of Electronic Systems Engineering
Indian Institute of Science, Bengaluru

Lecture - 28
Demonstration of MQ3 Gas sensor using Arduino

Hello, welcome to the Sensors and Actuators course, in today's session we will be seeing about an actuator which is called the stepper motor, we must have discussed earlier other actuators such as DC motor, the peristaltic pump then, so apart from other sensors also. in this tutorial, we will be showing you how to use a stepper motor which is a rotatory actuator.

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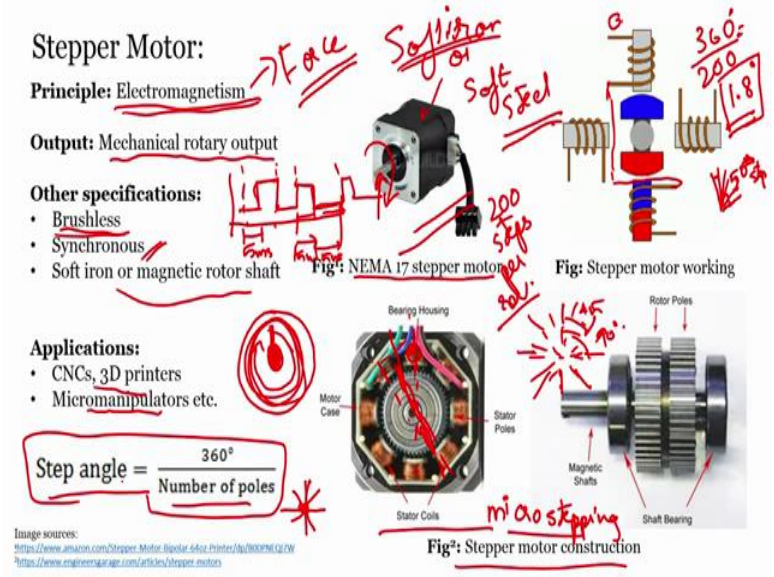

So, this is a different kind of motor as you can see in the presentation. the stepper motor is a different motor like our DC motor only you can see a stepper motor type of stepper motor named NEMA 17 stepper motor over here, You can see this black part with a black part is the body and this is the shaft that rotates,

So, this is the stepper motor this is an example of a standard stepper motor that is commercially available, what exactly is a stepper motor that we will be discussing now, You can see that this is the inside of the stepper motor these two pictures over here figure 2 shows the inside the construction of a stepper motor.

You can see here that there are coils over here correct you can see coils, you can see coils here, And there is something on the center a circular shape on the center and this is like the view

from this side that is if I call at the top view and then this is the view like out of this paper plane, so this is over here.

And you can see something over here also that has a cylindrical shape you can understand from the figure only, and this entire part is what that is going to sit inside this, you can see a motor case on the outside correct you can see a motor case you can see 4 wires, one green, one blue, one red one and black one coming out of the motor correct. Then you can we will see coils here one 2, 3, 4, 5, 6, 7, and 8 number of coils bound around correct.

, and it is fixed to the motor case right and it is and there is a circular thing on the center and which is over shown over here. This is the construction now I will tell each one what this is one of them are, these coils are called the stator coil these are called the stator coils and this is called the rotor and what there is in the center is the rotor.

So, as the name says the stator coils are stationary and the rotor rotates. rotor consist of the part that rotates inside the motor and stator coils are the fixed stationary part of the motor and this rotor will be having the shaft that is over here, the shaft comes out through this rotor hole this is how it is constructed and I will tell you what are the how it works,

And you can see here on the right side this is the construction of a rotor, so it has a shaft it is written magnetic shaft I will tell you how it is magnetic and in the later stage. you can see the shaft here you have a rotor pole, so the stator coils are around on this stator pole and there are rotor poles also, These poles as mentioned here are made up of material such as soft iron, or soft steel, these are magnetic materials generally paramagnetic materials,

So, these are these shaft are made up of soft iron and soft steel there are different types also I will let you know once we discuss further, one happens is, you can see there are 2 coils 4 wires coming here and each 2 of the wires will be connected to 2 or more stator poles, Before going to that I will show you how a stepper motor works and for which I will be going through different types of a stepper motor, so that you can get a better understanding,

So, before that, I will say that the principle stepper motor works on electromagnetism like most of the electric motors, it works on electromagnetism it means that when electricity electromagnetism is nothing but when electricity passes through a current-carrying conductor a magnetic field is generated. And this magnetic field will be able to create some force, force and which will be used to rotate the motor or any purpose.

So, based on electromagnetism the stepper motor will give a mechanical rotary output and when good things about the stepper motor are they are brushless the contact losses are very less the contact losses are very less and it is synchronous and it is synchronous. It means that whatever signal we give at a stipulated time or whatever signal that we give right now it is going to affect the motion of the stepper motor,

So, it does not have a lid (Refer Time: 06:09) or lab, so it is synchronous and it has a soft ion or magnetic rotor shaft soft iron rotor magnetic rotor shaft I will give you an idea about it. And CN CNC machines, 3D printers which are popular these days use stepper motors. Also, I have shown you, micromanipulators, these also use stepper motors inside it.

Then why stepper motors, so I will tell you. consider this is the shaft overview of the shaft and I am just drawing a circle here and I am putting something like a line here. And what happens is when the rotor rotates or the shaft rotates, this line is going to like come or rotate like this right in this line going to rotate about this shaft right here and it is going to complete a rotation.

In an ordinary DC motor what happens is it is like a continuous motion, so it is like keep on rotating it will keep on rotating. But, in a stepper motor it happens in steps like this is the shaft and this was the line it will rotate and come over here first. Then it will come here, it will come here, then here, then here, then here, then here and here and it completes a rotation, though I showed it like 8 different motions.

It is actually very continuous, very continuous in the sense the signal for rotating it; it will rotate in steps, but the steps will be close enough that we will not feel like it is going like a step by step motion, but it will be continuous only, but if this is how it works. Now, before going to further this thing I will go into the next slide where I will show you different types of stepper motors,

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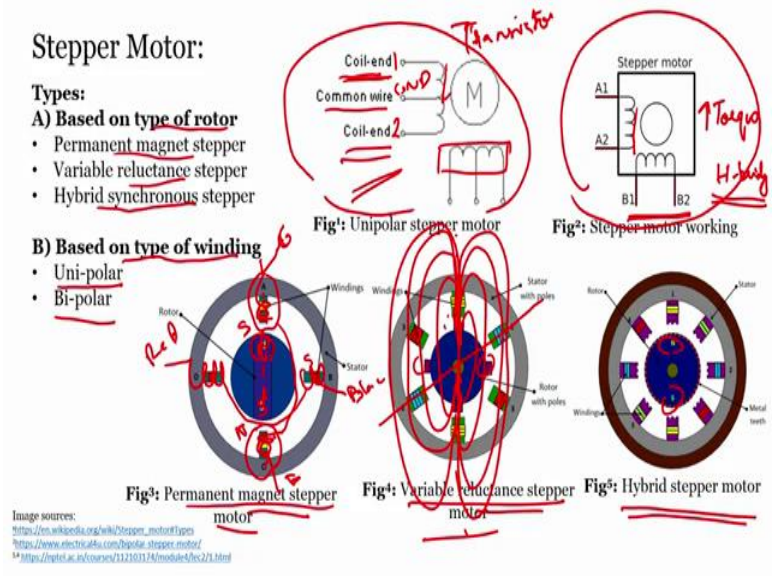

So, there are different types of a stepper motor and we classify them based on the type of rotor we can classify them as a permanent magnet stepper motor, variable reluctant stepper, and hybrid synchronous stepper, you can what do you can see here is this is the permanent magnet stepper motor; now I will tell you the concept of how it is working,

So, you can see here there is a winding A here and a winding C here, winding A and C and you can see that both of them are colored yellow here and both sides. And there is another stator B here and a stator C D which are also having the red color windings correct. it is like the cable comes there were 4 wires right it will be like the cable comes, it will rotate above this stator pole, it goes here it will rotate about this and go out.

So, what happens is one coil say the green one that we saw in the previous slide the green one; the green or blue is I just take telling an example green and blue are close and red and black are close. I will say the green wire over here will come here rotate around the pole go to the other pole rotate around it and will go out has to say blue wire. And similarly, a red cable will come from here it will go about this B pole and come out as a black wire.

So, what happens now is when I create a magnetic field when I pass the electricity through the coil G; G for the wire G. Then as you can see here when I pass through say G it can be connected it will be like it will be this wire will be connected over here, this is a different motor, but you can see here then individually like when I power this, this a current through this pole through

this coil. Then this pole will magnetize you can see it will be turning blue and red wire, blue is the South Pole and the N is the North Pole,

So, what happens is the shaft over here will also have a magnet in it this is an example of the permanent magnet stepper motor. It will have the North Pole as well the South Pole permanently on the rotor shaft. what happens is when I pass current through one of the coils what happens is here if there is the South Pole. If there is the South Pole created here then what happens is this South Pole will attract the North Pole of this motor correct. This South Pole and the North Pole be attracted and they will align, so then they will be close to each other, so this South Pole and the North Pole are attracted now.

Similarly, if this coil is continuous over here then there will be the South Pole there will be the North Pole created here and the South Pole already here, so this will also be attracted. now, this shaft over the central line of the stepper motors rotor with the magnet in it will be aligned with the poles correct, so it will be like in a straight line. Now, what happens is this is what happens when I pass current through G and it comes out through the blue line.

Now, suddenly I change the magnetic field by passing the current through B and the through the black and living in out through red what happens is this will magnetize. This North Pole will be attracted to the South Pole generator over here since we switch it off switch the current going through here and divert it through this coil. this North Pole will be attracted to as the South Pole and the motor shaft will rotate, so you will know how it works now.

So, if I change the polarity here if the motor shaft which was here will go here then will go here, so it can rotate a complete circle by means of 4 steps, so this is how a permanent magnet stepper motor works, now, you can see back here, there is a magnet in the center of center over here correct and when I pass current over here, this is the permanent magnet over here and this is the coil, so I am passing current through this.

So, this will be magnetized and it will attract initially then I suddenly switch the current and make it flow through this and the magnet will be attracted here. this is the method by which the stepper motor rotates so this is how a permanent magnet stepper motor works.

Similarly, there is another type of stepper motor called a variable reluctance stepper motor. Reluctance is similar to resistance, resistance is the opposition to the flow of current by its reluctance is the opposition to the flow of the magnetic field is what reluctance is.

So, what happens is whenever we pass current through a copper coil or any other coil or current-carrying conductor a magnetic field is generated. And this magnetic field, so if I pass the current through this the magnetic field will go like this right you must have studied in the lower classes correct it will create a magnetic field be created like this correct this is what generally is. what happens is, in this case, it will be connected like the center of the magnetic field will be going and a big magnetic field is created I will show you I am just erasing it off.

So, if a magnetic field is going through the center of this coil like this it will go infinitely and there will be another field generated like this, which will be smaller fields also inside. if a magnetic field generated like this rotor shaft over here will be acting such that it will always try to reduce the resistance or reluctance in the path,

So, the magnetic force field has to pass through this soft iron material and reach and go through this coil and complete the loop. The magnetic field has to complete the loop since magnetic fields are closed-loop, it will always try to reduce the resistance or the reluctance. what happens is if it is not aligned if the shaft or the soft iron core here is not aligned then the reluctance will be more.

So, what happens is the shaft will shaft and the or the rotor will be experiencing a force a magnetic force that will try to align it to the center of the coil or the center or the axis of the magnetic field that the reluctance will be minimum, so it will also cause the rotor to rotate. Now, if I switch the current flowing through it the magnetic field will be generated in this access, and the shaft will rotate again. This is a way variable reluctance stepper motor work this is how a variable reluctance stepper motor works.

Then there is something else called hybrid stepper motor which will have both permanent magnet inside it or so there will be poles, the here there are soft magnetic poles. Similarly, we will have soft iron call poles, so these stepper motors will have the advantages of both permanent magnet type and the variable reluctant times.

So, what are the positives and negatives? It is like since the stepper motor over here in the permanent magnet is here. the magnets are already fixed the permanent magnets are already fixed, so what only we can do is like we can change the current flowing through it correctly. If there will be a limitation to the number of magnets we can keep as well as the will affect the resolution or the number of steps it can move or how fine we can move.

So, since these stepper motors are widely used for applications such as 3D printer CNC we need them to move very precisely very accurately, Then NEMA 17 stepper motor that we showed here right, so it has 200 steps per revolution. That means, each 360^0 turn 360^0 turn will be divided into 200 steps approximately equal to or is equal to 1.8^0.

So, this stepper motor can rotate up to 1.8^0 steps, so it is accuracy will be like it can rotate like this small or even smaller than this. To rotate a 90^0 totally it will have to rotate how many times it will have to rotate like 50 times correct for rotating 90^0 will have to move 50 steps correct. 50 steps it has to move to complete 90^0, and to complete 360^0 it has to go like around 200 steps, so this is how a stepper motor works.

So, there are some other concepts also that I will explain to you, so this is how a stepper motor works. And now we are going back to another type we can classify based on the winding also we by which we can classify them as unipolar and bipolar. This is the circuit of the unipolar stepper motor, and this is the circuit of the bipolar stepper motor,

So, what you can see here is this is the same motor it will have 3 wire inputs, 3 wire inputs one is coil end 1, and common wire, and the coil end 2, and there is the other coil for magnetic magnetizing the rotor say it is there hm. Then what happens is if I pass current through coil end 1 it will be going out through the common wire, the common wire is like the ground.

So, the unipolar motor has 3 wires if I pass current through the coil and it will come out through the coil wire common wire which is kind of ground. And the status will be able to rotate in one direction correct or the magnetic field will be a magnetic field that will be created in one direction. And if I swap the current and current flows through the coil and 2 and go out through the common wire the magnetic field direction will be reversed.

So, in this case, to reverse the direction in which the motor is rotating, what we do is change the direction in which current flows or we will change the input coils that is how we control the direction. And in case of a bipolar stepper motor, it has 2 independent coils 2 independence coils A 1 and A 2 and B 1 and B 2. if I flow the current in one direction in through A 1 and a 2 motor will get it has in one direction and if I send the current in another direction, then it will rotate in the or magnetic field B grade in the opposite direction.

So, the main advantage of the stepper motor the bipolar stepper motor is that it will have higher torque. It is because 2 independent coils are there which could be connected to multiple stator

coils, but 2 independent coils and the current entirely flows through the entire length of the coil. The entire length of the coil current flows and the magnetic field will be stronger, but in this case, the current flows only through the half-length of the coil so the torque is actually less.

But the easy thing is using a simple transistor circuit we can actually switch the direction of the magnetic field in case of a unipolar thing using a simple transistor switch. Using a transistor switch we are able to switch the direction, but in this case, we need some delicate mechanisms such as an h bridge to properly switch between the lines and make this motor rotate,

So, this is the 2 types, the classifications are based on rotor we can classify them as a permanent magnet stepper motor, variable reluctance stepper motor, and hybrid synchronous stepper motor. While based on the type of winding we can call them as a unipolar stepper motor, and bipolar stepper motor I think you have got an idea. You can see a lot of YouTube videos that will explain it to you with more animated videos like that is shown here,

So, now, I hope you understand how a stepper motor works, and you can see here I have given an equation step angle is equal to 360 by the number of poles, the number of poles means we can create magnetic fields in that many directions correct. If I have 4 poles like this then I can create 1 and 2 correct, one magnetic field in this direction.

If I had 4 more poles then I can create like see, so I can increase the step where I can get a 45^0 precision step while in the previous case we can only get a 90^0 thing correct. If I increase the number of poles what happens is we will be able to get more accurate poles or the number of steps and reducing the step angle, the step angle can be reduced if we increase the number of poles.

Now, there is some other method that we do it electronically, so this is the constructional aspect of the stepper motor. We may not be using it exactly like this, so we could also use it in some other way by electronically controlling it. What we do it is, we can pass current through two different coils or two different stator coils at once by which there will be a magnetic field in this direction as well as the magnetic field in this direction. what happens is the resultant will be like this and the motor will align like this.

So, here we can see that if we polarized only this one the motor would have aligned the like this if we align like this one second. if we align these two motors the motor will align like this correct if we align these two stator coils and if you pass current through these two stators, the

motor will align like this. But if we power both of them together there will be a resultant and we can stop the motor like this also.

So, by means of electronically creating an artificial pole, an artificial pole is created here based on which we can get an extra step this is called micro-stepping. It is used for higher precision activities it is called as microstepping. for this we do this process by using an external electronic circuit or something like a motor driver and which will help us do microstepping, Microstepping is nothing but using the same stepper motors by exciting two coils at once we are able to get micro-steps. Now we will see the working of the stepper motor,

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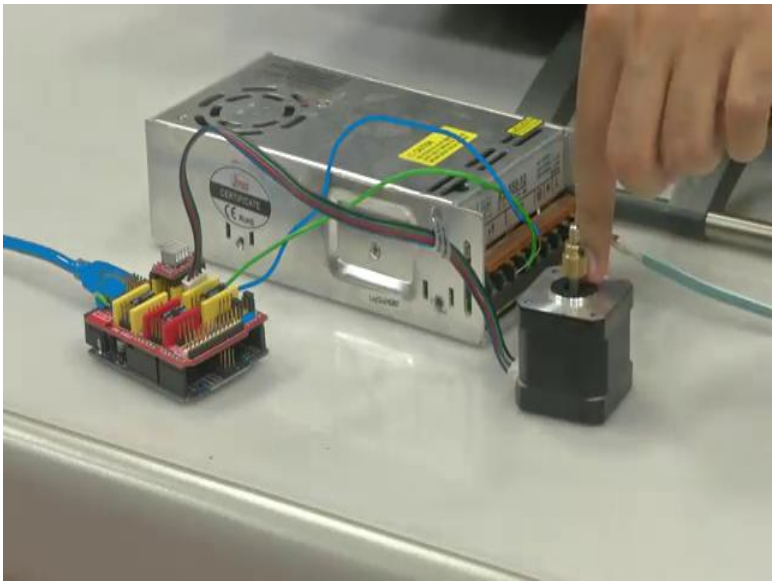

So, you can see here the stepper motor over here correct this is the NEMA seventeen stepper motor and I have got an SMBS here. This stepper motor request 12-volt power supply for it to work, so I connected an SMBS that can provide an output of twelve volts and it goes to a word over here this is an Arduino UNO board on the bottom and this is a CNC shield.

So, what are CNC shield? CNC shields are nothing but shields generally are some mountable electronic circuit Arduino boards are standard. if we are going to use an Arduino UNO say CNC machine, then what we can do is we could use a standard Arduino shield, using an standard Arduino shield which can be easily plugged in we can use it for different applications, so in this case we are using in this as a CNC shield,

So, we are using a shield that is used for such application there are different other shields also some line follower robots use a shield for that purpose; it can be like take an Arduino UNO to take a shield to insert it. the circuit is ready automatically the wires are all connected by PCB manufacturing.

So, we do not have to use any breadboards or we do not have to custom design any circuits, so shields are widely available for different applications. what we have used here is a CNC shield, this CNC shield Arduino CNC shield can you have control up to around 4 to 5 stepper motors we can control up to 5 stepper motors,

So, now what I show you say, motor driver, the CNC shield uses different motor drivers it is like a circuit like a breadboard. Which is or like hardwired and this one this is a motor driver which will be mounted still on above the Arduino CNC shield. this is F 1 9 double 8 motor driver is F 1 9 motor driver, so what it does is it takes input from the Arduino board and it will give an output to exit the coils inside the stepper motor,

So, the input of the driver is 2 simple signals, one is pulse and the other one is the direction or we also call it as a direction and step, step is like turn one step another step. it is like steps and the other one is direction clockwise or anticlockwise, and in case of Arduino we can do it in only 2 ways it is like high or low, high means it will rotate in one direction and low means it will rotate in another direction.

So, there will be 2 input to the motor driver over here it will be the direction as well as step and direction can be high or low or anticlockwise or clockwise. But the output we will be sent from the Arduino to this one will be high or low and it will understand that it is to swap the direction and the other one is like, we will be asking it to move steps and 4 which we will be using pulses.

If I create this much you can see this is a digital pulse this is the digital pulse. if the clock cycle starts here, so there is a low area here then the it goes up comes down here, Now, once entire cycle will be completed here correct or if we count it from here it will be like here low, so there is a high and there is a low for a certain duration correct there is a high and low for a certain duration, so this is a pole.

When the motor driver F 1 9 double 8 gets a single-pole, what happens is it will count it as one step. you send a pulse single pulse, it will rotate one step if you send another pulse it will take

another step and based on the direction pin or the direction signal that you have given already it will be changing the direction also.

So, you have you can change the direction as you wish and also you have to continuously send a pulse for it to rotate. Why it is important is if you send 200 pulses exactly or if you send 200 pulses exactly for this NEMA seventeen stepper motor it will rotate 200 steps and that is equal to 360^0. it is like perfectly accurate you send 100 steps 100 pulses then it will rotate 100 steps equal to 180^0.

So, it is pretty accurate and also by means of putting some or sorting some pins in the CNC shield, this F 1 9 double 8 even allows you to use up to 32 microstepping. 32 microstepping means one step that is around 1.8^0 in case of the NEMA 17 stepper motor can be further divided into 32 smaller steps,

So, that accurate kind of motion will be available with the F 1 9 double 8 motor driver and this CNC shield, I will not be showing you to the microstepping feature of the stepper motor, but I will be showing you a sample demo of how to control a stepper motor. you will get a lot of tutorials and other things, so you could just study from those, so we will go to the Arduino code now.

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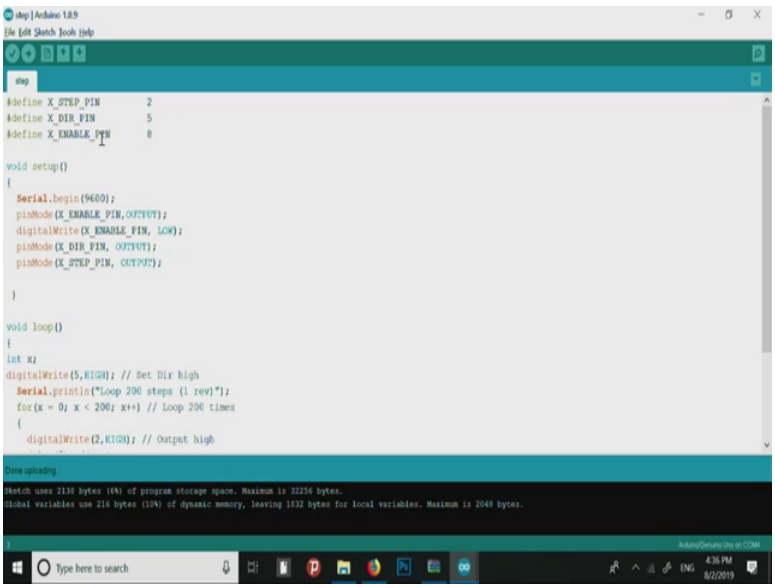

So, you can see the coding screen now, you can see the coding screen. I will increase the found a bit more say high so you can see now. As usual, we have a void setup right we have a void

setup over here correct and above which I have defined X STEP PIN. as I said there is 2 input to the stepper motor or the stepper motor driver that is F 1 and double 8 that we have used here. There is a lot of other motor drivers also this F 1 and double 8 has a current-carrying capacity of around 1.8 ambiguous.

So, if we are going for a higher power stepper motor, you can go to use some other motor drivers. And there will be plenty of heat generated when we use this stepper motor driver and every one of them will have a heat sink also over to transfer this heat into the air.

So, you can see here the 2 inputs to the motor driver are instep PIN and the DIRECTION PIN. in the STEP PIN, you have to give the pulses and in the DIRECTION PIN, you have to give other high or low to control the direction of the motor. And there is an ENABLE PIN, I do not think you have to care about that now ENABLE PIN is actually used to use for the CNC shield. This CNC shield is created such that if we for enabling the stepper motor say as I said this shield can control up to 5 stepper motors X Y Z and an X X (Refer Time: 32:56) one.

So, since this CNC shield, for it can be used for the 3D printer also. as I said that is why we denoted X, so I am connecting the stepper motor to the X motor driver or the motor driver as same to the X,

So, that pin is pin number 2 and pin number direction is pin number 5, and if I need to use that pin stepper motor connected to the motor driver X, I have to enable it and keep it as low, If I keep the ENABLE PIN low then only I will be able to control the stepper motor, it is done because see if the stepper motors we supply power to it. It will be powered on the magnetic field will be created, but only when we give the second pulse it will start rotating. But otherwise it will create a holding torque like a single pole will be magnetized completely or it will remain magnetized and it will prevent the motor from rotating, so it is actually taking some power correctly.

So, when we are not using all the stepper motors we need not waste our power that is why we have this feature. You use you enable it low only when you create the ENABLE PIN low only when you need to rotate in other or power it up otherwise keep it high so that it will not be powered up, so cool. the STEP PIN is 2 DIRECTION PIN is 5 and ENABLE PIN is 8 this is specific to this motor driver,

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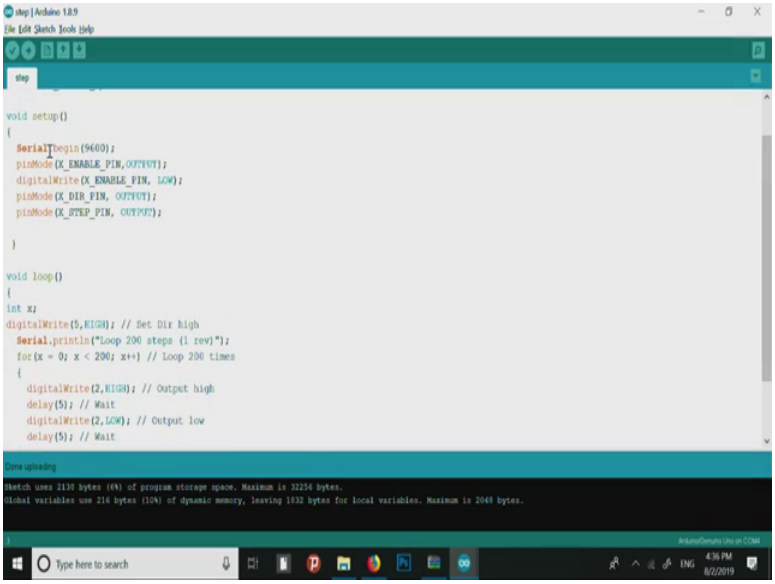

Now, inside the void setup I have started serial communication, it is not very important here I have been used it. And in the pinMode X, X should be output since it is X_ENABLE_PIN is output and I have made it low so that I want the motor to rotate completely I am not going to change it anyway. And pinMode (X_DIR_PIN , OUTPUT) (X_STEP_PIN , OUTPUT) you know this already,

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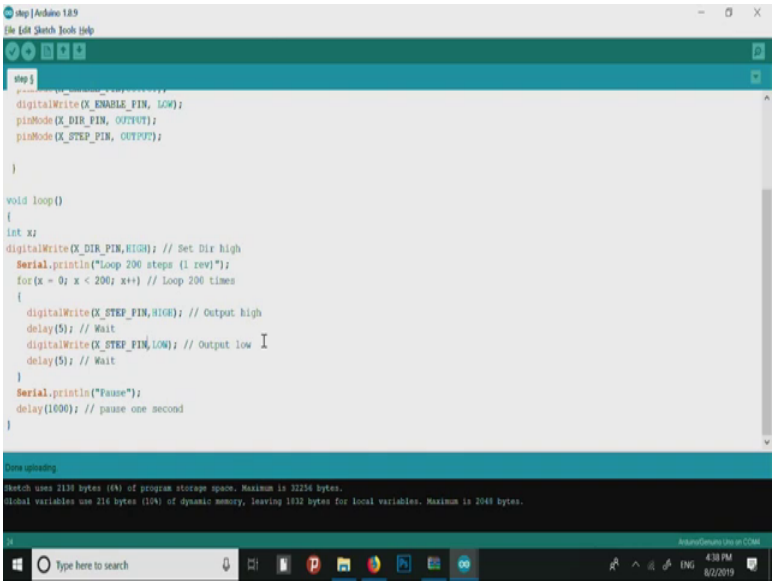

So, for creating a pulse I have used a simple method I put an integer X, I have put an integer X and digitalWrite(5, HIGH) 5 is nothing but X underscore direction pin. we already defined it

like that, so if even if we call it like that we define like this it should be working correctly. And what we will be doing is, I have put a far loop here with X equal to 0, X less than 200 and X ++ you know they are far loop, Now, I am going to create (2 , HIGH) or make it second pin HIGH, second pin is nothing but the (X_STEP PIN) .

So, if I make the STEP PIN high initially it was low, it will be low and then I delay for 5 milliseconds then I make it low and delay for 5 milliseconds again. I have actually generated a pulse I will write or show it here in the screen, this pulse for 5 milliseconds it you can see here actually this is a better way I may have I have made it high for 5 milliseconds I have made it low for 5 milliseconds once that is then the far loop will come again and will again make the pin high.

So, this is how a single pulse is generated, so every time the far loop goes for a next iteration a pulse is generated and how many times it will happen? It will happen 2 200 times from 0 to 199 correct 0 to 199. what happens is it will rotate 200 steps inside the for loop then it will delay for 1 second, so the motor will stop again then again it will start from the first part, the motor will be rotating 200 steps or equal to one rotation, then it will stop for a while around 1 second and then it will again start rotating. Now, we can see what happens when I upload the code, you can see the stepper motor now I am uploading the code I have uploaded the code now.

It is uploading, it is uploading is done now you can see that the stepper motor rotates it will rotate and comes is stop. You note this initial position, you see my finger is over here initially this black mark over here is where it will exactly come there correct see, so it is rotating 200 steps exactly every time it will be like this.

So, this is how a stepper motor works, I told you how it works this is a bipolar stepper motor you can see there are 4 cables, so it is a bipolar stepper motor. From the Arduino, it will get both directions as well step and the motor driver will convert and accordingly switch the coil and change the magnetism. this is stepper motor works.

So, I hope you understood this session on how is stepper motor works, so there are a different type of stepper motors which can be used for different applications the very common application that we see today out these days are the 3D printers. the 3D printers will be using like 5 stepper motors to control the XYZ movement as well as the extruders or extrude the plastic out,

So, there are like wide applications, so this is how a stepper motor works you can do use and try this, using different motor drivers. You need not using a CNC shield, but this say an easy way to do it, you can even create a circuit of your own and try it out, so that is it about the stepper motor demo.

Thank you.