Sensors and Actuators
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Lecture - 47
Basics of Stepper Motor and Demonstration using Arduino Microcontroller

Ok. Ready.

Student: Sir sure sir.

Hi welcome to this particular demo class again this is a Demonstration class where we will actually showing you the demo and this time we have taken an actuator, last time if you see we were talking about a sensor which was pressure sensor. So, when you have seen how he is applying the pressure and how can you see the change in the resistance or a voltage depending on what the parameter was. And again you understand that pressure sensors are of several type the one can be of resistive type second can be of capacitive type.

So, you need to understand that they are signal conditioning units would change depending on the type of the pressure sensor. In this class our focus is more on the actuators and we will show it you as a demo how to interface stepper motors with microcontroller. So, that you get understanding that if you have a actuator how can you use a controller to actuate ah this particular stepper motor, it is a short demo. However, since we need to start from scratch we have tried to put the details about, what are the stepper motors? What are types? And how we can interface it? How can how can you control or program the controller?

Arduino is just one controller, but there can be many right and later on if you really see the signal conditioning model. So, you will see that there would be lot of parts of a controller that we may not like to use it. In that case what can be alternatives? Alternative can be something like p sock. So, when you look into the parameters we will know and understand more about what are can be the alternative techniques of interfacing the controllers with the sensors or an actuator right. So, just look at the demo have an question feel free to shoot me an email or ask me through the forum and I will get back to you bye.

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

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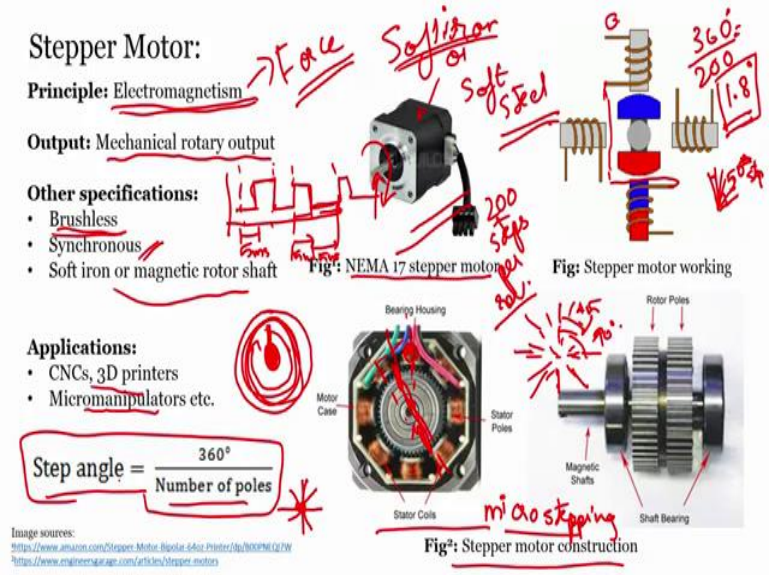

So, this is a different kind of motor as you can see on the presentation. So, stepper motor is a different motor like our DC motor only, you can see a say stepper motor a type of stepper motor named as NEMA 17 stepper motor over here ok, you can see this black part with a black part is the body and this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

So, this is the stepper motor a this is an example of a standard stepper motor that is commercially available ok. So, what exactly is a stepper motor that we will be discussing know ok. We can see that this is the inside of the stepper motor, these 2 pictures over here. The 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 here coils here ok.

And there is a there is something on the centre a circular shape on the centre and this is like the view from this side that is ok, if I call it the top view and then this is the view like out of this paper plane ok. 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 and their part is what that is going to sit inside this ok.

So, 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 and you can see coils here 1 2 3 4 5 6 7 and 8 number of coils bound around correct yeah and it is fixed to the motor case right and it is and there is a circular thing on the centre and which is over shown over here correct. So, this is the construction now I will tell each one what these each one of them are ok.

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

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 the later stage. So, you can see the shaft here you have a rotor poles. So, the stator coils are round on the stator poles and there are rotor poles also ok. This poles as mentioned here are made up of material such as soft iron, soft iron or soft steel these are magnetic materials ok; these are magnetic materials generally paramagnetic materials ok. So, these are these shaft are made up of soft iron or soft steel. There are different types also I will let you know once we discuss further ok.

So, what happens is you can see there are 2 coils 4 wires coming here and each 2 of the wires will be connected to two's or more stator poles ok, before go into that I will show you how a stepper motor works and for which I will be going through different types of stepper motor so, that you can get a better understanding ok. So, before that I will say that the principle of a stepper motor works on electromagnetism like most of them electric motors he works on electromagnetism. It means that when electricity electromagnetism is nothing, but when a electricity passes through a current carrying conductor a magnetic field is generated and this magnetic field will be able to create some 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 then good things about the stepper motor are they are brushless they are brushless.

So, the contact losses are very less; the contact losses are very less and it is synchronous. It means that whatever signal we give at a stipulated time or a whatever signal that we give right now it is going to affect the motion of the stepper motor ok. So, it does not have any delay or lag ok. So, it is synchronous and it has a soft iron or magnetic rotor shaft soft iron or rotor magnetic rotor shaft I will give you an idea about it.

And CNC machines, 3 D printers which are popular these days use stepper motors, also I have shown you micro manipulators this also use stepper motors inside it. Then, why stepper motors? So, I will tell you, so, consider this is the shaft overview of the shaft and I am just doing 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 this line is going to rotate about this shaft right here and it is going to complete the rotation.

In a 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 ok. And this was the line it will rotate and come out 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 it is different motion it is actually very continuous, very continuous in the sense once we give 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 this is how it works ok. Now, before going to further this thing I will go into the next slide where I will show you different types of stepper motors ok.

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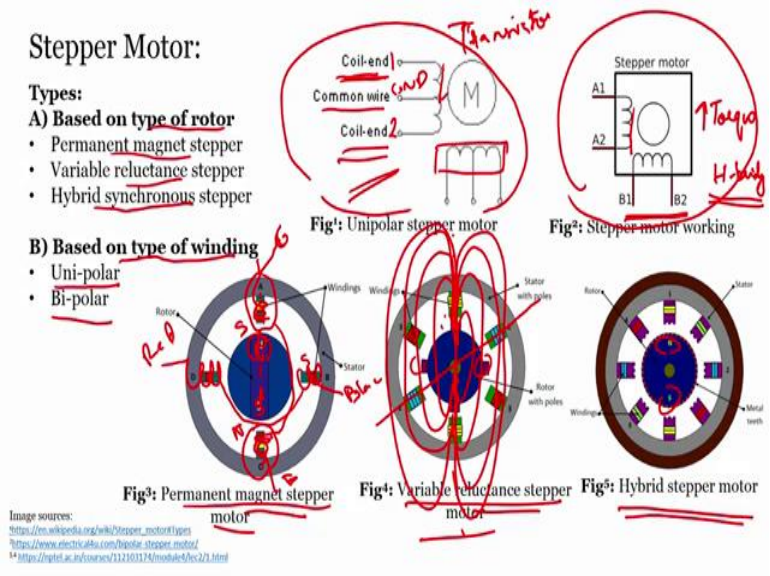

So, there are different types of stepper motor and we classify them based on type of the rotor based on the type of the rotor we can classify them as, permanent magnet stepper motor, variable reluctance stepper and hybrid synchronous stepper ok. So, you can what you can see here is, this is the permanent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

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 on both sides right and there is another stator B here and a stator C, D which are also having the red colour windings correct. So, it is like the cable comes ok, there were 4 wires right it will be like the cable comes you will rotate about this stator pole it go 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 one I am just telling an example green and blue are closed and red and black are closed right. So, I will say the green wire over here we will come here, rotate around the pole, go to the other pole rotate around it and we will go out as say blue wire and similarly a red cable will come from here it will go about this B pole and come out as the black wire.

So, what happens now is when I create a magnetic field when I pass the electricity through the coil G or the wire G, then as you can see here ok, when I pass through say G it can be connected it will be like it will be this wire will be connected over here ok. So,

this a different motor, but you can see here that individually like when I power this, this and current through this, pole through this coil then this pole will be magnetized, you can see it will be turning blue and red right blue is the South pole and the N is the North pole ok.

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. So, it will have a North Pole as well South Pole a permanently on the rotor shaft. So, what happens is when I pass current through one of the coil what happens is, here if there is a south pole ok. If there is a South Pole created here then what happens is this South Pole will attract the North Pole of this motor correct.

The South Pole and North Pole will be attracted and they will align so, that they will be close to each other ok. So, this South Pole and North Pole are attracted now. Similarly if this coil is continuous over here then there will be a South Pole yeah there will be a North Pole created here and a South Pole already here so, this will also be attracted.

So, now this shaft over the central line of the stepper motors rotor with a 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 leaving into out through red, what happens is this will magnetize right.

So, 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 diverted through this coil. So, this North Pole will be attracted towards the South Pole and the motor shaft will rotate ok. So, you know how it works now. So, if I change the polarity here 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 ok. So, this is how a permanent magnet stepper motor works ok.

So, now, you can see back here you can see that there is a permanent magnet in the center of center over here correct and when I pass current over here ok. So, 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. So, this is the method by which the stepper motor rotates cool.

So, this is how a permanent magnet stepper motor works; permanent magnet stepper motor works. Similarly there is another type of stepper motor called as variable reluctance stepper motor. Reluctancy is similar to resistance ok, resistance is the opposition to the flow of current while reluctance is the opposition to the flow of magnetic field to the flow of 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 right.

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 be create a magnetic field will be created like this correct, this is what generally is. So, what happens is in this case it will be connected like the centre 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 centre of this coil like this it will go infinitely and there will be another field generated like this there will be a smaller field also inside ok. So, if magnetic field is generated like this, this rotor shaft over here will be acting such that it will always try to reduce the resistance or reluctance in the path ok. So, the magnetic force field has to pass through this soft iron material and reach and go through this coil and complete the loop right the magnetic field has to complete the loop since magnetic fields are closed loop ok. So, it will always try to reduce the resistance or the reluctance.

So, 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 or the rotor will be experiencing a force a magnetic force that will try to align it to the centre of the coil or the centre of or the axis of the magnetic field so 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 axis and the shaft will rotate again, this is how a variable reluctance stepper motor work; this is how a variable reluctance stepper motor works.

Then there is something else called as hybrid stepper motor which will have both permanent magnet inside it also there will be poles, the here there are soft magnetic poles right. Similarly we will have soft iron core poles so, these stepper motors will have the advantages of both permanent magnet type and the variable reluctance types. So, what are the positives and negatives? It is like since the stepper motor over here in the permanent magnet is here.

So, 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 correct. So, if there will be limitation to the number of magnets we can keep as well as the which will affect the resolution or the number of steps it can move or how fine we can move. So, since the stepper motors are widely used for application such as 3 D printer CNC we need them to move very precisely very accurately ok.

The NEMA 17 stepper motor that we showed here right so, it has 200 steps per revolution steps per revolution 200 steps per revolution; that means, each 360 degree turn 360 degree turn will be divided into 200 steps approximately equal to or is equal to 1.8 degree. So, this stepper motor can rotate up to 1.0 degree steps ok. So, it is accuracy will be like can rotate like this small or even smaller than this.

So, to rotate a 90 degree totally it will have to rotate how many times, it will have to rotates like 50 times correct. For rotating 90 degree it will have to move 50 steps correct, 50 steps it has to move to complete 90 degree and to complete 360 degree it has to go like around 200 steps. So, this is how a stepper motor works.

So, there is some other concept also that I will explain to you. So, this is how a stepper motor works and now we are going back to the another type we can classify based on the winding also, we by the which we can classify them as uni-polar and bi-polar this is the circuit of the uni-polar stepper motor and this is the circuit of the bi-polar stepper motor ok. So, what you can see here is, this is the say motor it will have 3 wire inputs 3 wire inputs, one is coil end 1 and common wire and a coil end 2.

And there is the other coil for magnetizing the rotor say it is there, then what happens is if I pass current through coil end 1 it will be going out through common wire common wire is like the ground. So, the uni-polar motor it 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 a ground

and the stators will be able to rotate in one direction correct. Or the magnetic field will be; magnetic field will be created in one direction and if I swap the current and current flows through the coil end 2 and goes out through the common wire the magnetic and field direction will be reversed.

So, in this case to reverse the direction in which the motor is rotating what we do is we change the direction in which current flows or by we will change the input coils that is how we control the direction. And in case of a bi-polar stepper motor, it has 2 independent coils; 2 independent coils A 1 and A 2 and B 1 and B 2. So, if I flow current in one direction in through A 1 and A 2 the motor will get magnetized in one direction and if I send the current in other direction then it will rotate in the or magnetic field will be greater in the opposite direction.

So, the main advantage of the stepper motor the bi-polar 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 uni-polar thing using a simple transistor switch, you see a transistor switch we are able to switch the direction, but in this case we need some delicate mechanisms like such as an H bridge to properly switch between the lines and make this motor rotate ok.

So, this is the 2 types the classifications are based on rotor, we can classify them as 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 uni-polar stepper motor and bi-polar stepper motor. I think you have got an idea ok, you can see a lot of YouTube videos that will explain it to you with more animated videos like that is shown here ok.

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 number of poles ok. So, more number of poles means we can create magnetic fields in that many direction correct, if I have 4

poles like this then I can create 1 and 2 correct, one magnetic field in this direction, one magnetic field in this direction if I have 4 more poles then I can create like see.

So, I can increase the step here I can get a 45 degree precision step while in the previous case we can get only a 90 degree thing correct. If I can increase more number of poles what happens is we will be able to get more accurate poles or number of steps and reducing the step angle ok, 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. So, we may not be using it exactly like this. So, we could also use it in some other way by electronically controlling in it. So, what we does is we can pass current through 2 different coils or 2 different stator coils at once by which there will be a magnetic field in this direction as well as magnetic field in this direction.

So, what happens is the resultant will be like this and the motor will align like this. So, here you can see that if we polarize only this one, the motor would have aligned like this if we align like this one second. So, if we align these 2 motors the motor will align like this correct if we align these 2 stator coils and if we pass current through this 2 stator the motor will align like this, but if we power both of them together their 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 as micro stepping this is called as micro stepping.

So, micro stepping is used for higher precision activities it is called as micro stepping. So, for this we do this process by using an external electronic circuit or something like a motor driver and which will help us do micro stepping ok. Micro stepping is nothing, but using the same stepper motors by exciting 2 coils at once we are able to get micro steps good ok. Now, we will see the working of the stepper motor ok.

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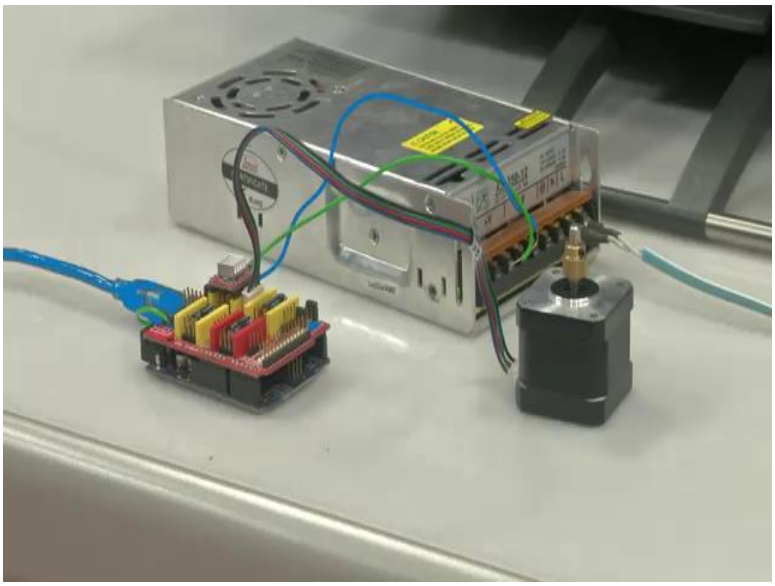

So, you can see here; you can see the stepper motor over here correct this is the NEMA 17 stepper motor and I have got an SMPS here this stepper motor requires 12 volt power supply for it to work. So, I connected a SMPS that can provide an output of 12 volt and it goes to a board over here this is an arduino uno board on the bottom and this is a CNC shield.

So, what are CNC shields? CNC shields are nothing, but shields generally are some mountable electronic circuit ok. Arduino boards are standard so, if we are going to use an arduino uno as a CNC machine then what we can do is, we could use a standard arduino shield ok. So, you see 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 ok

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 take a shield insert it. So, the circuit is ready automatically the wires are all connected by PCB manufacturing ok.

So, we do not have to use any bread boards or we do not have to custom design any circuits. So, shields are widely available for different application. So, what we have used here is a CNC shield, this CNC shield arduino CNC shield can control up to around 4 to 5 stepper motors ok, we can control up to 5 stepper motors ok.

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So, now what I will show you is a motor driver the, the CNC shield uses different motor drivers it is like a circuit like a breadboard. So, which is all like hardwired and this one this is a motor driver which will be mounted still above the arduino CNC shield. So, this is a A 4988 motor driver, it is a motor driver. So, what it does is, it takes input from the arduino board and it will give an output to excite the coils inside the stepper motor ok.

So, the input of the driver is 2 symbol signals, one is pulse and the other one is direction or we also call it as direction and step ok, step is like turn one step another step another step. So, it is like steps and the other one is direction clockwise or anticlockwise ok. 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 direction as well as step and direction can be high or low or anticlockwise or clockwise. But the output we will be sending 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 for which we will be using pulses ok. I send one pulse, pulse is something like I can see here see I am just creating see if I create this much you can see this is a digital pulse this is a digital pulse.

So, if the clock cycle starts here ok. 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 counted 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 a low for a certain duration. So, this is a pulse when the motor driver A 4998 gets a single pulse what happens is, it will count it as one step. So, you send a pulse single pulse it will rotate one step, if you send another pulse it will rotate 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. So, why it is important is, if you send 200 pulse exactly or if it send 200 pulse exactly for this NEMA 17 stepper motor it will rotate 200 steps and that is equal to 360 degree. So, it is like perfectly accurate, you send 100 pulses then it will rotate 100 steps equal to 180 degree. So, it is like pretty accurate and also by means of putting some or shortening some pins in the CNC shield this F 1188 even allows you to use up to 32 micro stepping, 32 micro stepping means one step that is around 1.8 degree in case of the NEMA 17 stepper motor can be further divided into 32 smaller steps ok.

So, that accurate kind of motion will be available with the F 1988 motor driver and this CNC shield I would not be showing you the microscopic features of the stepper motor, but I will be showing you a sample demo of how to control a stepper motor. So, you will get a lot of tutorials and other things. So, you could just study from this ok. So, we will go to the arduino code now.

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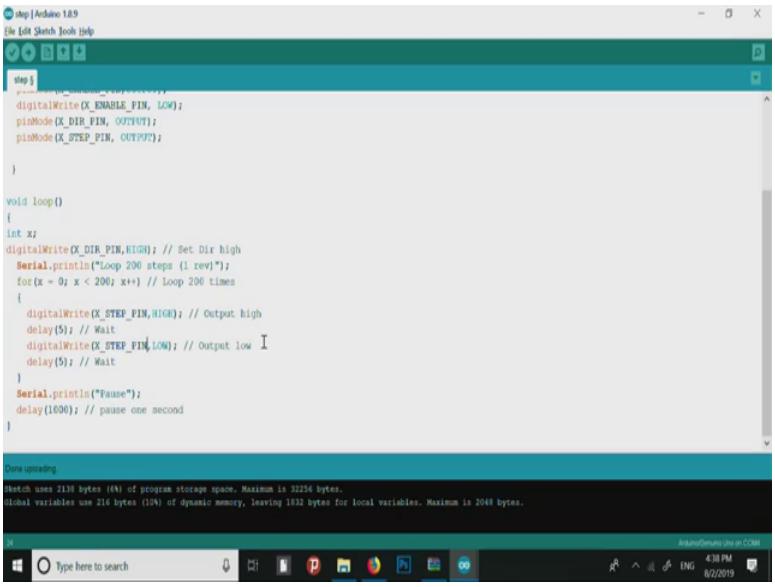

So, you can see the coding screen now, you can see the coding screen right yeah I will increase the font a bit more say high good. So, you can see now. So, as usual we have a void setup right yeah we have a void setup over here correct.

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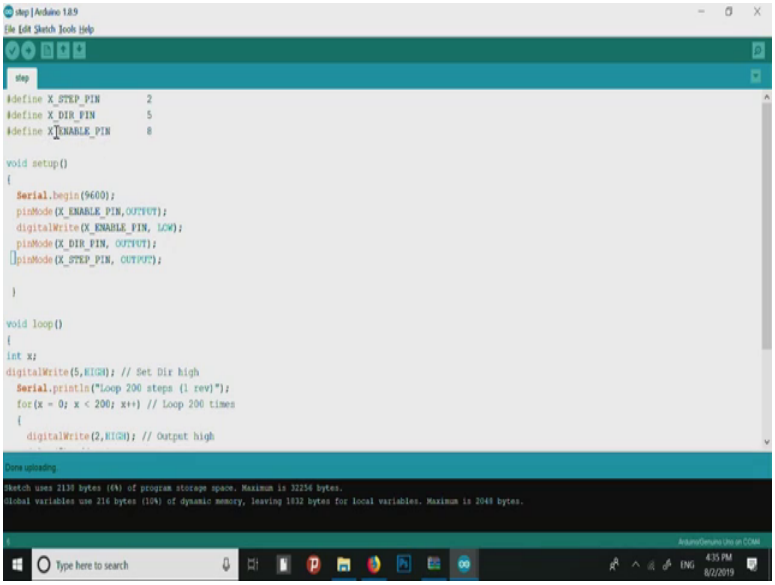

And above which I have defined X STEP PIN. So, I said there is 2 input to the stepper motor or the stepper motor driver that is F 1988 that we have used here there are a lot of other motor drivers also, this F 1988 has a current carrying capacity of around 1.8 amperes. So, if we are going for a higher power stepper motor you can go to use some other motor drivers ok. And there will be plenty of heat generated when we use this stepper motor drivers and every one of them will have a heat sink also to transfer this heat into the air ok.

So, you can see here the 2 inputs to the motor driver are STEP PIN and the DIRECTION PIN. So, 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, the CNC shield is created such that if we for enabling the stepper motor ok.

Enabling the stepper motor say as I said the this shield can control up to 5 stepper motors xyz and nx extruder 1. So, since this a CNC shield for it can be used for 3 D printers

also. So, 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 assigned to the X ok.

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 ok, I have to enable it and keep it as LOW ok. 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 if 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 correct.

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 it or power it up otherwise keep it high. So, that it would not be powered good. So, the step pin is 2, the action pin is 5 and enable pin is 8 this is specific to this motor driver ok.

Now, inside the void setup I have started serial communication it is not very important here I have not used it and in the pin mode X, X should be an output, since it is X enable pin an output, I have made it low. So, that I want that motor to rotate completely I am not going to change it anyway and pin mode X direction pin comma output, a step pin comma output, you know this already ok.

So, for creating a pulse I have used a simple method I put an integer x and digital write 5 comma high, 5 is nothing, but X underscore direction PIN right. So, we already defined it like that. So, if even if we call it like that we define like this it should be working correct and what we will be doing is I have put a for loop here with x equal to 0, x less than 200 and x plus plus you know, therefore, loop ok.

Now, I am going to create 2 comma high or make the second pin high second pin is nothing, but the x step pin correct x step pin correct yeah. So, if I make the step pin high initially it was low ok, it will be low and then I delay for 5 millisecond then I make it low

and delay for 5 millisecond again. So, I have actually generated a pulse I will write or show it here in the screen ok.

So, this pulse for 5 millisecond you can see here actually this is a better way I have made it high for 5 millisecond I have made it low for 5 millisecond once that is done the for loop will come again and will again make the pin high. So, this is how a single pulse is generated. So, every time the for loop goes for an extra iteration a pulse is generated and how many times it will happen, it will happen 200 times from 0 to 199 correct 0 to 199.

So, what happens is it will rotate 200 steps inside this for loop, then it will delay for one second. So, the motor will stop again then again it will start from the first part ok. So, the motor will be rotating 200 steps or equal to one rotation then it will stop for a while around one 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 ok.

It is uploading yeah it is uploading is done, now you can see that the stepper motor rotates it will rotate and comes to a stop in not this initial position you see my finger is over here initially this black mark over here is here 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 bi-polar stepper motor you can see there are 4 cables. So, it is a bi-polar stepper motor.

So, from the arduino it will get both direction as well as step and the motor driver we will convert and accordingly switch the coil and change the magnetism. So, this a stepper motor how it works. So, I hope you understood this session on how a stepper motor works. So, there are different types of stepper motors which can be used for different other applications the very common application that we see today or these days are the 3 D printers. So, the 3 D printers will be using like 5 stepper motors to control the xyz say movement as well as the extruders or extrude the plastic out ok. So, they 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 use a CNC shield, but this is a easy way to do it you can even create a circuit of your own and try it out ok. So, that is it about the stepper motor demo.

Thank you.