NPTEL Online Certification Courses
Industrial Robotics: Theories for Implementation
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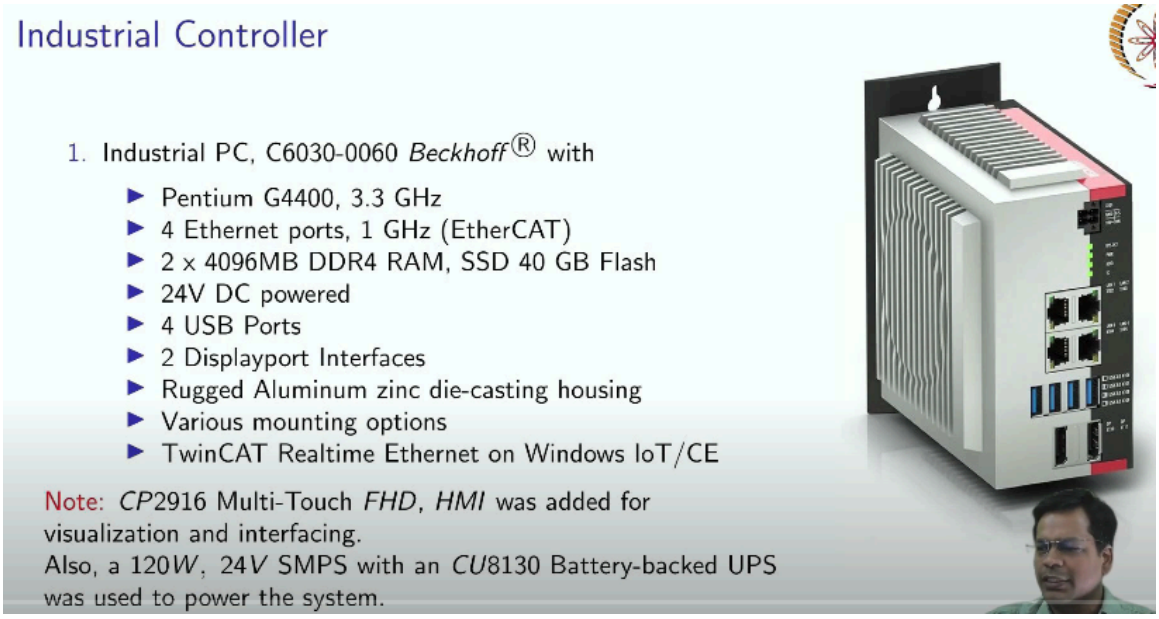
Introduction to Industrial Controllers, Drives and Systems

Hello, and welcome back. So, in today's lecture, before we actually begin into the further modules which are Actuator and Sensor, I want to introduce you all to a very huge difference which is there in Amateur Robotics and Industrial Robotics. Most of the time, when we start working, we start thinking with the same old background that we have, that is - Start with an Arduino, start with a small microcontroller like MSP430, Raspberry Pi and that stuff. And when we graduated, we also got introduced to some of the IO cards which were maybe some NI IO cards or PCI DAC or some other type of DAC system, which let us communicate with external devices using IO cards. So, that is what we commonly call Data Acquisition Systems. So, using that, we could very well communicate with industrial systems.

But having that only in industry may be very difficult to go ahead with. Why? Because they are not industrially compliant sometimes, they are not standardised to be an industrial product most of the time. I would not call it so because quite a lot of NI DAC cards are also industrially safe. But yes, when it comes to compatibility with many other systems which are there in the industry, it becomes very difficult to expand your system to accommodate all the various requirements which are there, that you might face in the industry. To communicate with your robot, say, to communicate with IO cards, to communicate with other sensors, actuators mostly the drivers and industrial PCs, it becomes very difficult. So let us just introduce you all to industrial kinds of data acquisition systems. Yes, it is a type of data acquisition system, and it also has an industrial PC. So, without talking much, let us move ahead.



So yes, this is what you see is a type of industrial PC which is from Beckhoff. It is known as the C6030 series. So, you see, this PC has got this type of configuration, it is Pentium. So, long back, we have been working with Pentium on our desktops, yes, but why is Pentium still there in the industry? Because you know the industry doesn't go so fast. Yes, i7 processors with four cores are also available, but they are extremely expensive. We don't need it, actually. Most of the time, we want to do real-time communication between our devices, input-output systems, and drivers. Let us say I am moving a robot in a trajectory; I should be getting feedback every moment in milliseconds or sometimes microsecond rate, and having even a single millisecond delay sometimes kills our system.

So, we want to work with real-time systems. We want to accommodate other input-output cards which are there. At the same time, we want to be very economical. That is probably one of the reasons that didn't let the industry grow too much in terms of the processing power and those kinds of stuff. But yes, we can manage very well with just one single processor. Can you imagine, even with a Pentium G4400, 3.3 GHz? It is still GHz! It is of so high frequency if at all I can count on its clock frequency; if I can convert this GHz frequency processor to, let us say, 1 GHz communication from my sensor, I am done. I don't need it further. So, I want to use 100% of my processing capability. So, that is the reason I should be happy with 3.3 GHz if I can work with the whole of the 3.3 GHz. So, my OS is not capturing the processing capability. My GUI is not taking into account that other applications which are running behind are not that computationally expensive, which is scaling my processor capability.

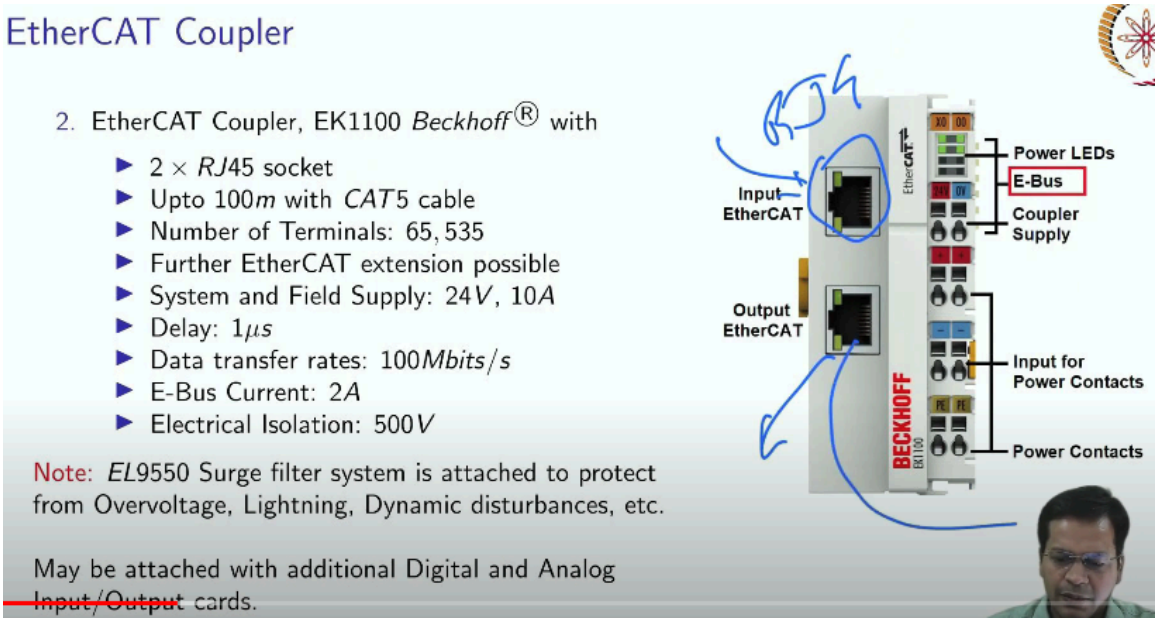
It also has 4 Ethernet ports. If you can see here, these are there. These are Ethernet ports. So, although it looks like Ethernet, they are EtherCAT compatible. It can work with 1

GHz LAN, and it has a very small amount of memory that is 2 x 4096MB, almost 8 GB RAM, DDR4 RAM and SSD is its hard disk you can call it. Yes, it is only 40 GB, but it is quite good enough. It only has to store the temporary data which is running behind; sometimes, the software which is running in the real-time system, which is handled over here, is the TwinCAT system. It can be VXworks, it can be RTOS or something else. So, only that is the application which is running behind that is to handle the real-time stuff.

Apart from that, your OS is there, and that is not killing too much space. So, yes, this is quite good enough. It is 24-volt power, you see. It has some 24-volt input over here, which can be fed from here, and it runs everything with that 24-volt. It has 4 USB ports. Yes, you can see it clearly. It is here. So, that is USB ports. Ruggedised aluminium zinc die-casting housing. They are very, very rugged to handle industrial environments, and they can dissipate power heat very easily. So, that is the reason it is made up of such material to absorb vibration as well as to transfer heat. So, various mounting options are there. It can be mounted on a standard DIN rail-based system and many others.

So, various mounting options are there, and this can run TwinCAT real-time Ethernet which is a Beckhoff proprietary software to handle real-time communication between devices that are connected, and the background normally uses Windows IoT or Windows CE over there. So yes, this can be integrated; what I have used for my demonstration also is a multi-touch FHD (Full HD) display which is a human-machine interface that was added for visualising the stuff. I can see what is going behind, maybe I can have a SCADA somewhere in front of me so that I can touch and operate my system, get some values and show them on the screen, and so forth. So, that is the reason it is there, and it also has a 120-watt 24-volt SMPS with a CU8130 battery-backed UPS. UPS is there for the same old reason. Your system should not shut down immediately if there is any power failure. That is the reason it is here also. It is a 24-volt input UPS with a 24-volt output.

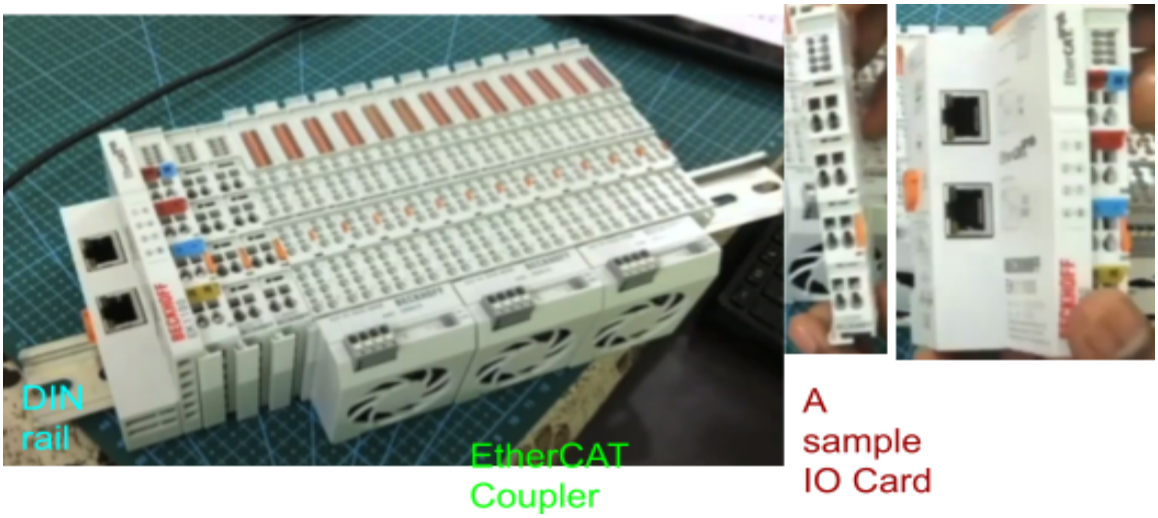
In the industry, all the supplies are normally 24 volts, so that is the reason I used to power up my system. So yes, industrial controllers and industrial PCs are like this. They look like this. They do not look like traditional PCs, but yes, this works. Sometimes, they are DIN rail-mounted; sometimes, they also have DIN rail-mounted PCs with add-on cards. You can keep on adding cards to it, those options are also there. So, this is a type of industrial controller. We call it a controller, although it is a PC because it is the one handling all my IO systems, and maybe it has the kinematics of my code. The Kinematics part of the program may be handling the closed-loop operations which are there. So, that is the reason it is known as the controller.



There is a very good stuff known as the EtherCAT Coupler. It is a type of coupler to do some sort of industrial communication. You see, it has an input Ethernet. It looks like Ethernet. It is an Ethernet protocol, which we commonly call EtherCAT. It is again a Bechoff proprietary. We will talk about the different types of Ethernet-based communication systems after these few slides, and there is an output EtherCAT also.

So, yes, it has two RJ45s. These are RJ45 sockets. So, with this, you can extend these devices, and maybe you can have multiple such devices. We can further add IO add-on cards on top of it. So I will show you that, do not worry. The number of extensions you can keep on adding cards on top of this is as much as 65,535. If you remember, this is the value of int, so that is 65,535 and further EtherCAT extension is possible. You can have IO modules that can be fitted after this, one by one, that can go here, or maybe you can further attach a similar EK1100 after this and extend your devices further. So you can keep on adding that, so that is how.

So yes, now you also have a system field bus supply 24 volt 10 amp. So after this, it has a field bus E-bus connector that transmits the continuity. Let me just show you one of such cards, which is there with me right now.

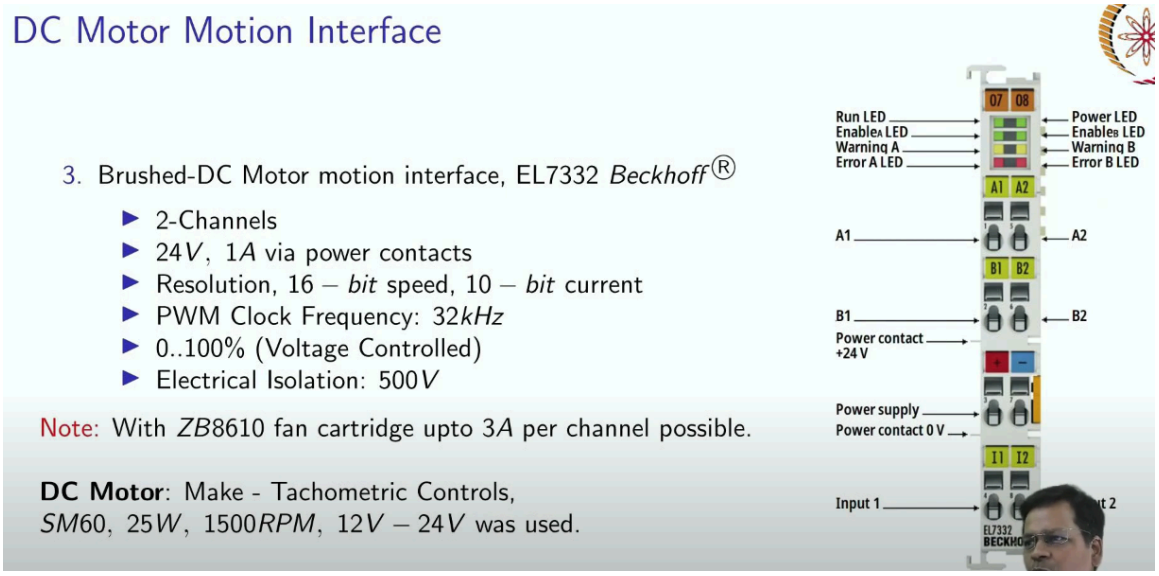


Maybe I can show you right now at the moment. So this is one such system that I have in my hand, which you can see. So this is your EtherCAT coupler. You see, this is a coupler that looks like this. It has two Ethernet ports here, so this is the DIN rail, which is normally mounted in the control panel inside so that you can plug in all the cards after this so you see how it goes. So this is your EtherCAT coupler. So, see how it was fitted to the DIN rail. It simply went in here, and you can simply push it so you see some contacts are here. Those contacts establish their connection with this. So, once you connect this, you slide it on top of this, and it immediately gets connected to the rest of the system, which is there in the bus. It is not that easy to put in. So now you see it has gone in.

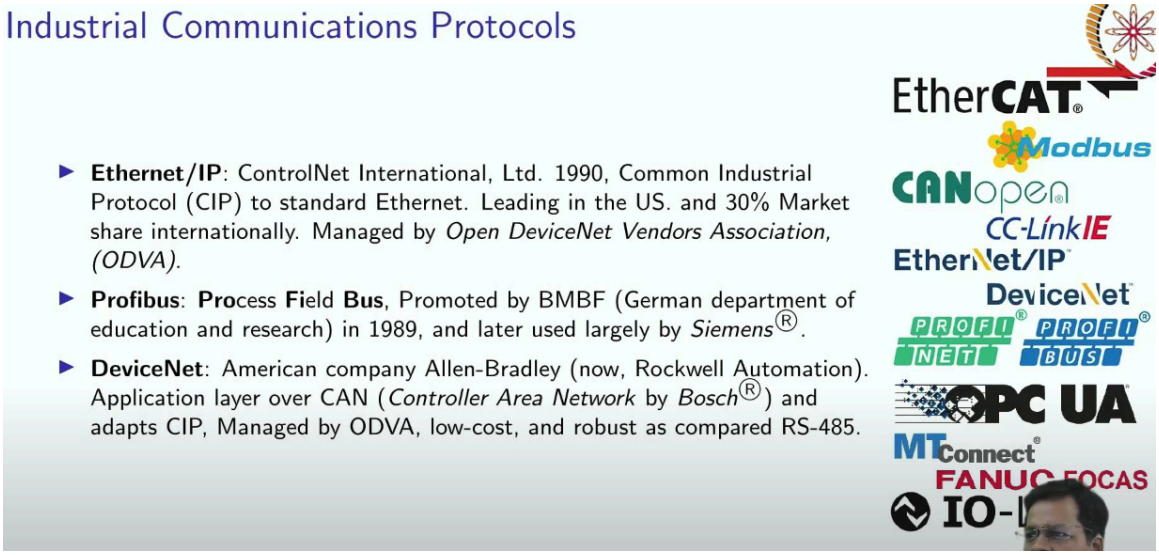
So, there are methods to lock it. Also, if you see clearly, there is a lock that can be locked like this to the DIN rail. If you unplug it, you can push it. Now it has found its slot, and now you can lock it. So, same way, I can pull out any of the cards which are there. You see, I can simply pull out one of the cards that are here. So, these are the different IO cards. They are very, very modular. So, all these cards have some specific function; they are known as IO cards.

Sometimes, they are motor drivers for digital input-output. For analogue input-output to running a motor, to interfacing, let us say, a strain gauge force sensor, or many other kinds of sensors. So this is just one card that I have just pulled out from in between. If you just push it back, it will go, Okay, so, now it has been plugged in. So all the devices which are here are one by one they have specific functions. So hope you got the view of this; I will discuss it further when we come to it. So, the first thing that was there was one of the search filters, EL9550. That is a surge filter system, so the power comes into this. From this, it goes to the controller, so that any sort of overvoltage, lighting, or dynamic disturbances which are there in the supply can be simply eliminated. So, that is why it is

there and maybe attached with digital analog and digital input-output cards, which are there.



Now, going to the next. It is one of the brush DC motor motion interfaces that is EL7332. That is, again, a Beckhoff one, so it also has a DC motor interface. So, if I do not know or if you can read it clearly. They are EL7223, which is the DC servo motor controller. I will be working with the DC motor controller also. It does not have that card in particular. So, each of them has an add-on module which increases its power rating, and then you have this type of small fan system which is there that enhances its further current carrying capacity. So, this is the way it is fitted. So, it goes to its slot, so they need external connections again. These are some of the IO cards.



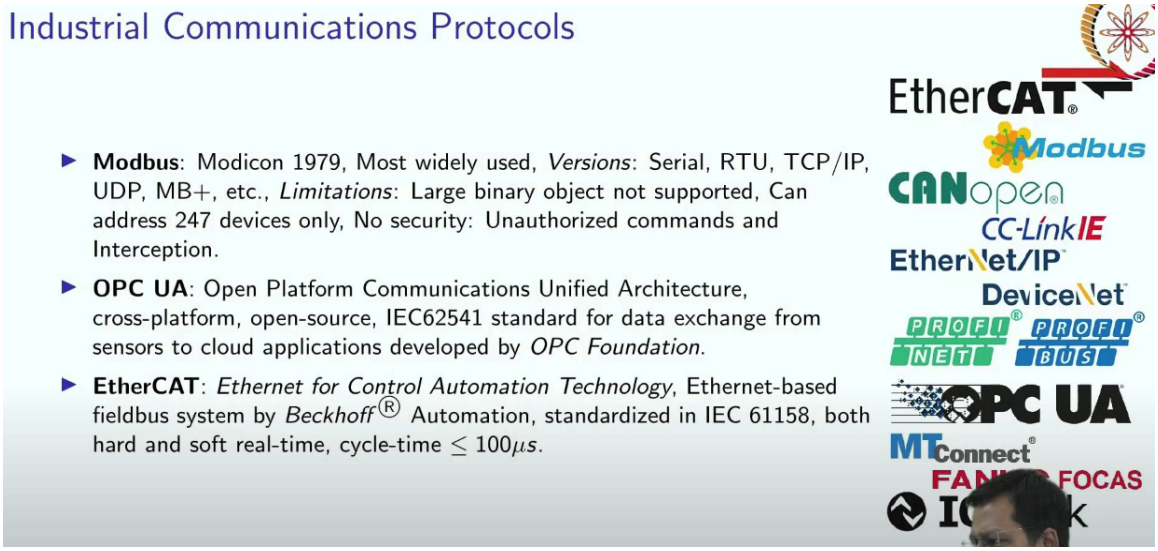
Industrial communication follows EtherCAT. There are many other types of Internet communication, communication networks, and industrial communication protocols. Why

is it important? Because an industry system should be very reliable against any sort of undeclared commands if that goes in, any sort of interception if that happens from over the internet if it is connected. So, that should be very, very safe, and you should be electrically safe also to take care of any sort of electrical noise for long-distance communication and so forth. So, that is the reason. So, there are many established protocols which are there. Some are based on serial protocols, some are Ethernet-based protocols, some are proprietary developments, and some are general developments for the world, which is now open for the world.

It is an Ethernet IP. Control Net International Limited developed this in 1990, which is a common industrial protocol to standard Ethernet leading in the US. This particular protocol is very popular in industry in the US, and also, 30% of international markets here are by EthernetIP-based system. So, that is a communication network that you have seen you had something which was there earlier. Now, over here, you had an Ethernet-look-like thing. Now, this can be EtherCAT; this can be various other types of things. So, this is a controller, control thing, and then it is managed by the Open DeviceNet Vendors Association, commonly known as ODVA. So, now, this protocol is open to the world; nothing is just proprietary. So, it is used by various other makers apart from Control Net International. So, any other company they are making their devices can make their devices compatible with this also. So, that is one, and then you have a Profibus system: Process Field Bus System, promoted by BMRF (German Department of Education and Research). It was established in 1989 and, later on, used largely by Simmons. Simmons is a global manufacturer of different types of IO cards and PLC-based systems. So, everything that you see in industrial automation, most of the things are now made by Simmons also. So, Profibus is one such protocol which is followed in the world. These are some of the symbols which are there. Some of the commonly used logos of each one of them. So, this is for EtherCAT, which is a profile proprietary of Beckhoff. Now, it is again open to the world. Other companies are also using it. Modbus is there CAN open cc link, IE EtherCAT IP DeviceNet. So, we'll talk about each one of them.

So, the next is DeviceNet, which was established by an American company called Allen Bradley, and now it is Rockwell Automation. Application layer over CAN bus, i.e. Controller Area Network that was established by Bosch. So, initially, it was there, now it has this application layer, and now it also adapts CIP, which is the Common Industrial Protocol for this. It is again managed by ODB. These are a few of the network protocols like Ethernet IP device net. These are a few which are managed by open-source things. Open, not open source. It is basically managed by an open DeviceNet vendor association. They are low-cost and cost-robust as compared to RS-485 is very, very similar to RS 232, which we commonly call serial port UART or USART type of communication, which is

commonly used with Arduino and those stuff. So, it is just a level higher based on RS 485. It is a DeviceNet.

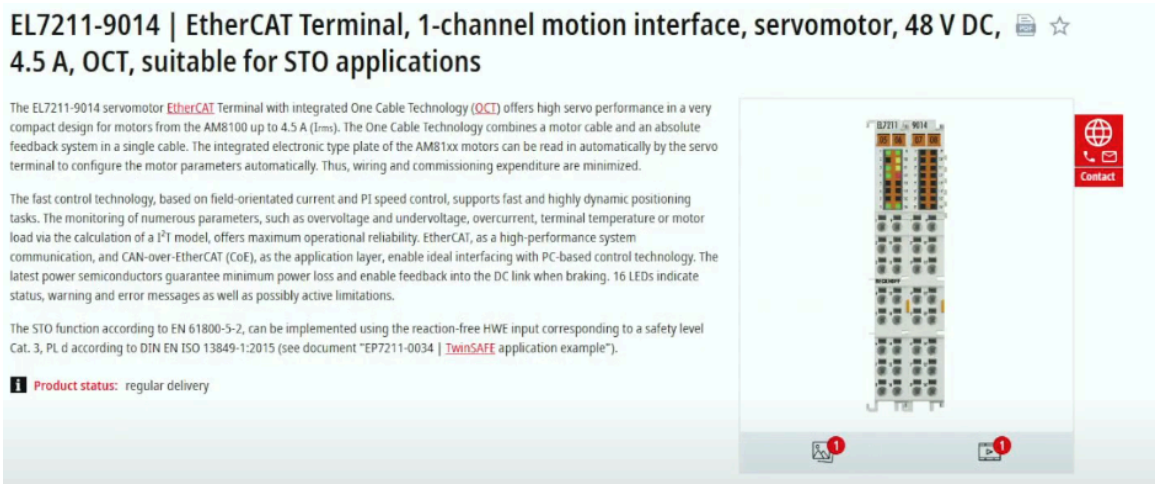


Okay, and then you also have a very common, very widely used, and that is a protocol which is mostly used over in industry is MODBUS protocol. Developed by Modicon in 1979. The most widely used versions are serial. It started with a serial. Now, it is RTU that is a three-wire communication kind of thing, and TCP IP is again a type of Ethernet based system UDP. UDP is also there, and then UDP is a very commonly used protocol in Ethernet. So, Modbus plus communication is there. They have some limitations there because it was developed somewhere in 1979. It was very much limited with bandwidth, that is, the number of bits of its operation. So, large binary objects are not supported. So, it can handle only 247 devices as compared to EtherCAT devices. It has some 65535 devices. So, that is a 16-bit system; maybe this is just an 8-bit system for addressing. So, it has very less or no security at all. So, one-to-one connected unauthorised commands are acceptable and can even be intercepted, but yes, they can carry long-range transmission, and it is pretty safe and used widely in the industry, and most of the devices support this. So, there is one very good thing about this kind of protocol.

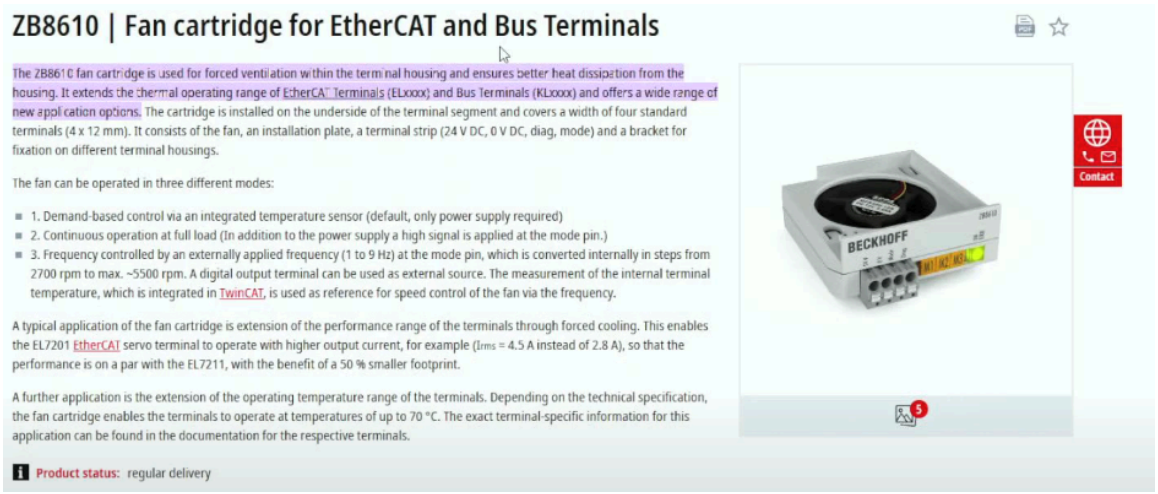
One of the protocols is Open Platform Communication Unified Architecture. It is commonly known as OPC UA. It is a cross-platform development. It is not dependent on any type of OS on which it is working. Let's say it can work on Linux, it can work on Ubuntu, it can work on Windows, Windows IOT or Mac sometimes. So, it is also open source and IEC62541 standard for data exchange from sensors to cloud communication applications developed by the OPC foundation. So, it is defined over there, okay, so this is open source also. If somebody is looking to develop their own devices they can simply adapt this kind of open definitions which are existing. So, you can develop your device, which is now acceptable to the industry.

So, an EtherCAT: definitely EtherCAT is one of the best because it targets a real-time operation. It has a closed loop cycle frequency of something around 100 microseconds or less. So, it is a Beckhoff proprietary, which is now commonly used by many other makers. Ethernet for control automation technology is CAT Ethernet. So, the Ethernet-based field bus system developed by Beckhoff automation is standardised again in IEC61158. Both hard and soft real-time is possible. Hardware is mostly real-time; they have very low clock frequency, a very high frequency of communication they can do, sorry. So, that is what they can do, but yes, it also has the capability to work on software with some real-time stuff. So, they have a layer on top of it that can implement this, which is TwinCAT, as they commonly call it. So, TwinCAT is a layer that reserves one of the processors to do some real kind of stuff. So, even that can be installed on a standard PC, and it can do real-time communication. So, that is one beauty about it.

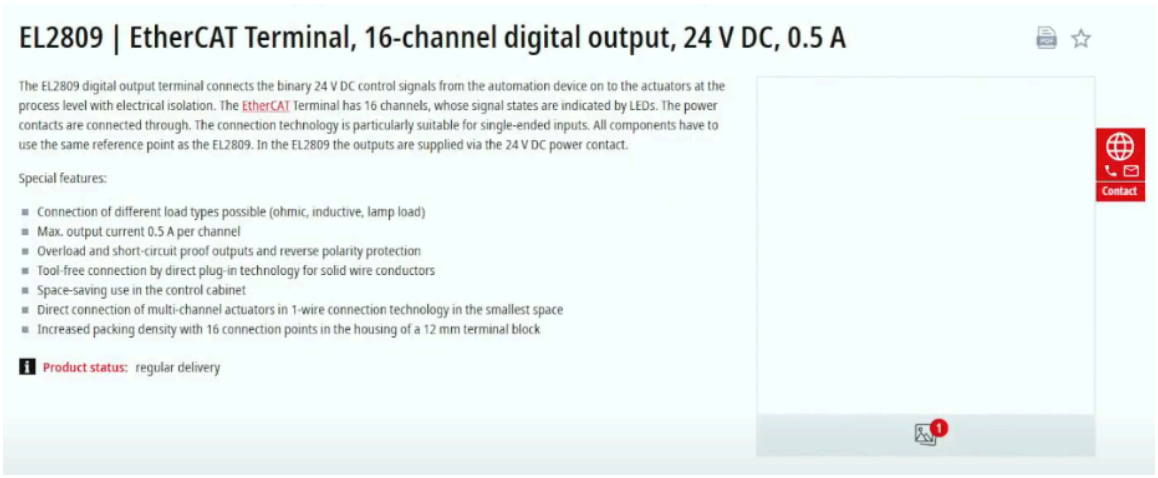
So, with this, yes, this is one of the introductions that I gave you for this. Apart from this, not just this kind of stuff, there is an EtherCAT-based system that is done by Beckhoff with good industrial compliance. So, all sorts of cards you can fit. So, what are all the cards which are here? I will quickly show you here, maybe. So, if you can go here, I am talking about this one, so they had this card that is EtherCAT terminal one.

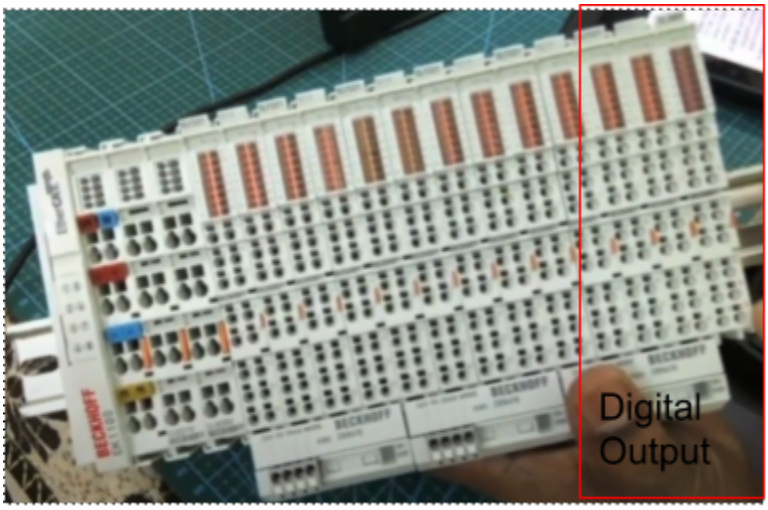


Now, channel motion interface servo motors: so yes, it was here. So, these were the servo motor interfaces. I wanted to interface with almost six servo motors. So, they are accommodated here one by one.



Another one in the queue is this one, so that is the fan cartridge that you saw. It is the fan cartridge that adds on to the servo drives so that you can run it at a higher current rating,



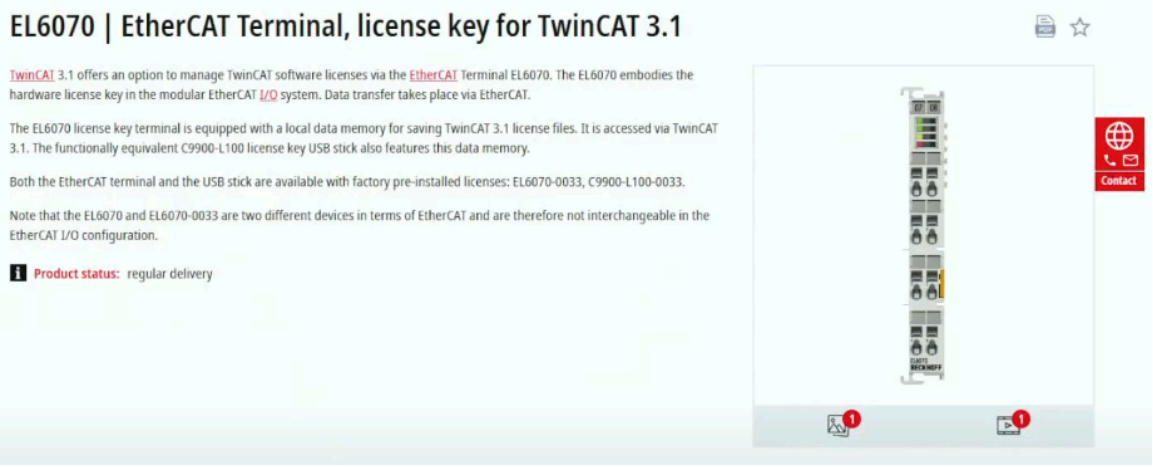


End Bus Connector

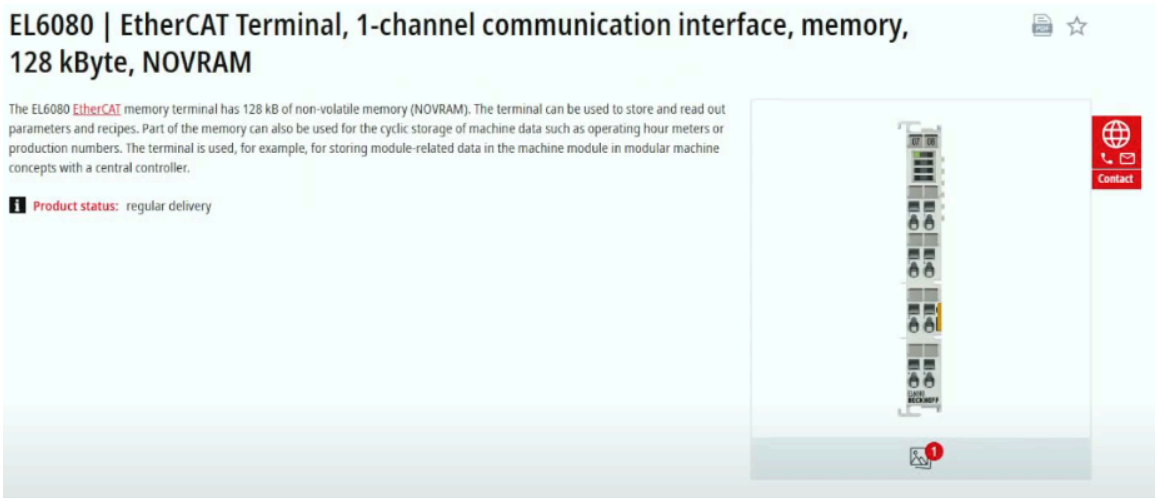
and then you have another device, which is the EtherCAT terminal, which is a 16-channel digital output that is at the end, which was there. So, that is the one, so the last one in the

queue is this card, which can take in all sorts of digital output from your 16-channel digital output from here. So, all are connected one after the other, and you can extend this to 65535 cards. Can you imagine and then you can put all those cards in series with some other EtherCAT couplers? So, you can see how many devices you can integrate.

Then, you have an End bus connector. So, that is again very, very common. So, in the end, you see, this is the one. So, this is the one which is there EL9011 that is the bus cover. Normally, the terminal should not be left open. So, at the end, the terminal is covered using that. It is just a cover, nothing else.



Another one is this one. So, that is an EL6070 is an EtherCAT terminal that is the licence for a licence key for the EtherCAT. I told you, it is proprietary software. TwinCAT is proprietary software that allows you to do real things, so it also comes with a licence, which Beckhoff and resellers sell. So, this is the one.



The last one which I had here is this one. So, that is the EL6080 EtherCAT terminal, a one-channel communication interface for the memory. So, I wanted my memory to be extended as well. So, this is additional memory for the runtime operation also that is there. So, you saw this is one of the very popular IO systems which is there.

Now, I will talk about a similar one, so all industrial systems are almost similar. I will show you yet another one that I have in hand. Now, yes, I will again switch on my camera here. So, you see, this is the power supply, which is also DIN rail mountable. This time, the way it is connected is through this. I can pull it out, and it comes out of the DIN rail okay. So, again, you have a similar one. It is a Modbus protocol. So, these two Ethernet ports are for Modbus.

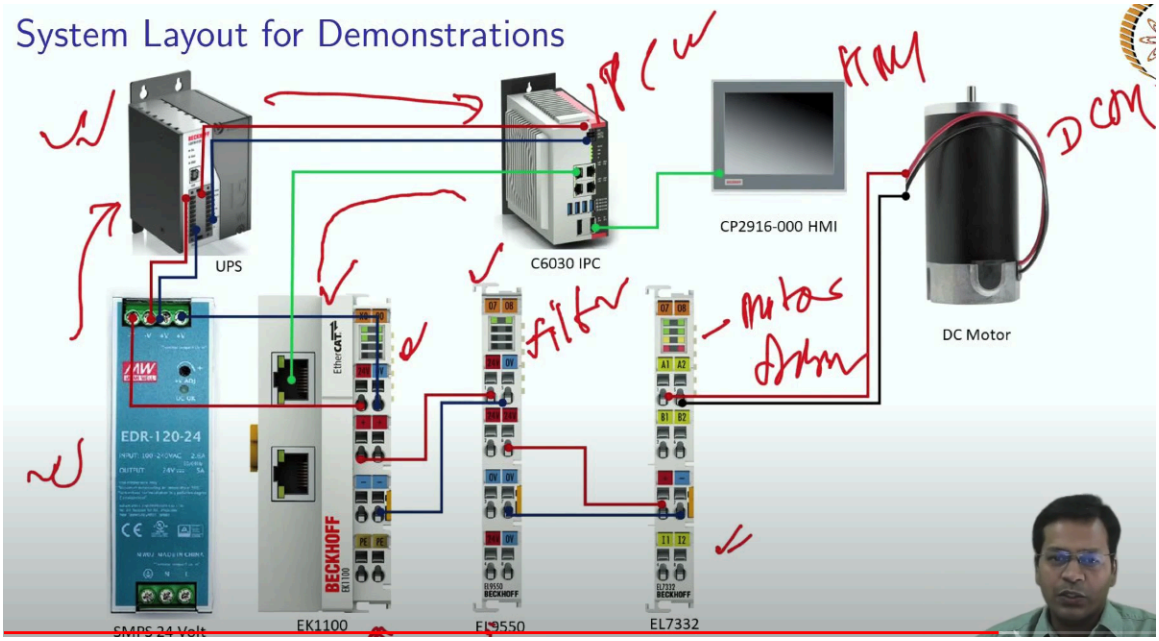
I will show you the actual thing now. Yes, this is a Modbus TCP network adapter, so this is here. Quickly can look at it so this also can be taken out like this. So, this time, the way it was connected to the DIN rail is something different. so it holds these two pins. They hold the DIN rail, and it can be taken out. See, now it holds, and now it is released holds. So, that is the way and it can be plugged in very easily again back to the system. So, this is how it is fitted, and then you have the same way you have multiple numbers of IO cards which are fitted one of the other. So, there are many similar systems. Again, I will show you one by one all the cards which are fitted here, okay? So, this is one of them, and then.

I have a card which is called a 16-channel digital input card CT-121. CT-121 is the digital output card,

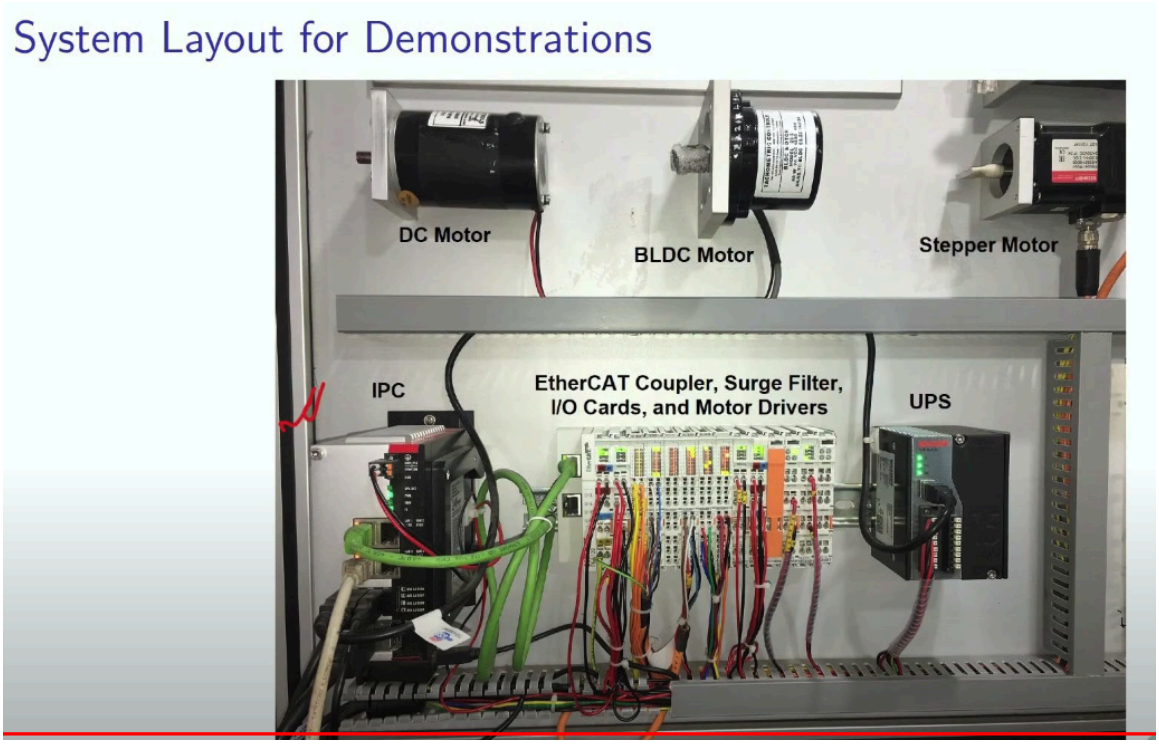
and there is a 16-channel digital output,

and then you have an eight-channel voltage output.

Again, you have RTD, which is for the temperature interface which is there. So, you see an input-output digital input digital output. So, all sorts of things can be done from these types of arrangements you see. So yes, all these can be mounted on your control system. So now this lets you communicate to your system. It lets you communicate to your PC, so now you can have all sorts of controller designs okay. The way I have designed for many many other stuff. I will show you one, okay? one so now you can build your demonstration.

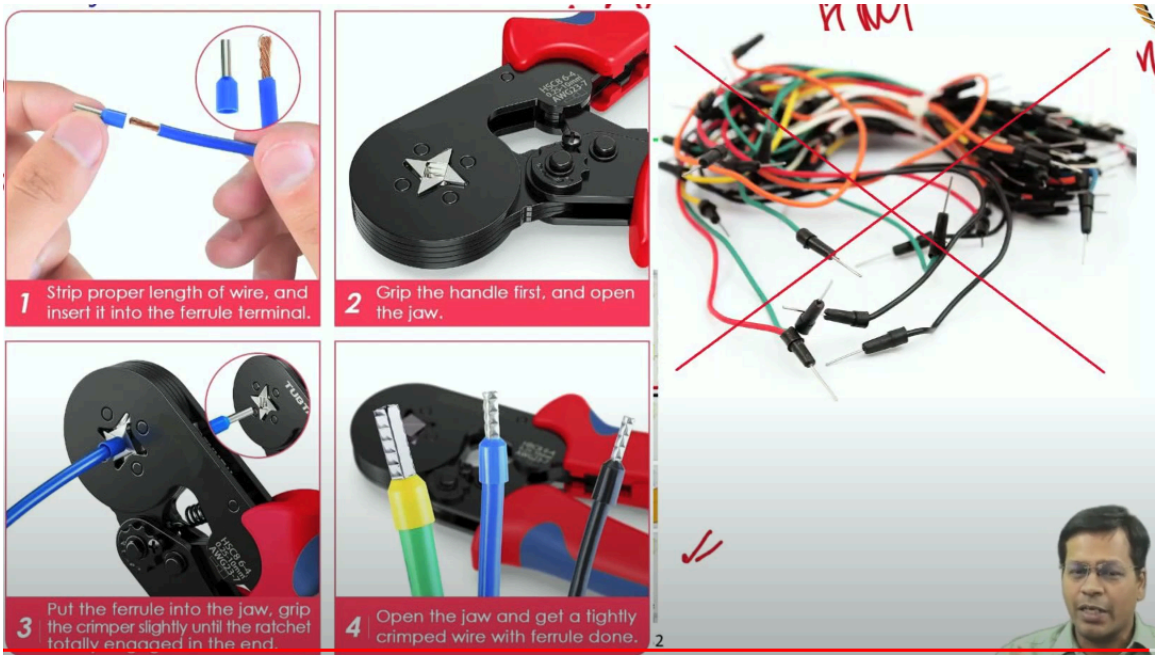


So, one such demonstration was this where I used a coupler okay. It is a filter. It is the filter which was there for the Beckhoff system. I will show you now. So, that is the filter, so I must keep this one here. So, yes, this is the way it was. So, one by one, different cards are there. It is your EK 1100, which is the EtherCAT communication protocol interface. EtherCAT to communicate with different people. It is the coupler for IO cards. So, IO cards go one after the other. So, this is the coupler. It is an IO card. It is a filter, and this is your motor driver. So, you see, you have a PC, which is an industrial PC here, and you have HMI, which is where we have HMI here, and this is your DC motor. It can be anything, not just this motor. It can even be a servo motor, a stepper motor, maybe a sensor or any sort of stuff. It is the UPS. So, from your external power source, it goes to the UPS, and from UPS, it goes to the industrial PC, and the PC finally communicates through this channel to the IO cards. IO cards are both input and output. So, from the filter, it is powered so that you don't see any noise that goes to the IO cards. So, you see, this is how you get bi-directional. You can do bi-directional communication. You can create a closed-loop system on your PC which works in real-time. So, that is how you can design a hardware controller. It is the reason why industrial systems are so different because they are very, very rugged.



Yes, this is how when it comes to building a system. I created an actuator demo which will be covered in this course using this. So, this is your UPS again. It is your UPS. This is your IPC industrial PC. It is your UPS, and that is powered through an external power supply which is lying somewhere else. That is a 220-volt to 24-volt supply that is powering this one, and then you have the EtherCAT system, which has EtherCAT couplers which connect all the IO card motor drivers. It is powered by a surge filter to discard any sort of electrical noise, and all the motor drivers are fitted here, one after the others, so this is how I am controlling all of them using my PC. So, I can do it even without an industrial PC. I can do it even without an industrial PC, mind it. It can go, so instead of using an industrial PC like this, I can simply remove this. I can put my standard PC, and I can still communicate using EtherCAT. In that case, you just need to have a Profibus card fitted on your system in your PCI slot, or maybe you can just have an Ethernet card, and you can implement at least Modbus and EtherCAT, which easily through this. Okay, through your standard Ethernet card and then in these IO cards, these Ethernet couplers, these manufacturers also provide APIs for their software and Modbus. They are normally free over the Internet. You will get plenty of good amount of drivers which can communicate. But yes, you have to go thoroughly with the datasheet of Modbus communication before you actually make such controllers. So, yes, that was not the motive behind explaining all these to you, and this is to expose you to the kind of difference which exists in the industry. The way we were brought up during my undergraduate days. Now, when I go to industry, I have to handle all this. So, this is where this course will create a difference, you know. Now, you should stop rather than using your old IO cards, and. Yes, you can definitely do academic stuff, but when it

comes to industrial robotics and industrial IO systems, industrial sensors, actuators, and other systems are in the queue. So, you have to take care, and you don't have to use your Arduino board. You see, your washing machine is not delivered with an Arduino board. Maybe the industry is not using Raspberry Pi. I won't say that firmly over here because maybe, at times, people do fit, but it is not practically safe to do it. So, that is the reason. So, industry, they run on all these drivers, and you have to be very, very familiar with this stuff. So that you can create your control system, which is very, very safe and can be directly deployed to industrial software.



Last but not least, and most importantly, you should start using this kind of wire. You know, most of my projects and the products that I make normally use this kind of wire, and you also should start using it. It consists of each one of them. You see, it has two ends. Each end is now fitted with a kind of lugs which fit like a cap. Okay, and you have a crimping tool with which you can just press in, and you can make customised length wires of quality copper conducting wires, okay? So, get used to it. I have seen mostly in hobby electronics amateur robotics and competitions that normally students use kind of jumper wires which are very, very unreliable. Most of the projects fail because of that. So, they can connect unreliably. So, with this, they have a dedicated even my motor driver, which has dedicated sockets over there. You see if it is here. It has a dedicated socket, which is here. So, these sockets know they. You can just press it in using a standard screwdriver kind of thing, and you just push it, and it gets fitted very well and even the terminal boxes have similar kind of thing. So, they connect very reliably, so connections are very, very important. Wires are very, very important, so take care. You should use proper wires also for your projects, that's all okay.

So, that's all the introduction for this. So, after this, I will be covering actuators that will be using similar setups. The Same amount of DC motor I have shown you here. It will only be used for the DC motor. I will come back to this once again when I will be covering the DC motor. I will be using a stepper motor with this. I will be running a servo motor with this. In this type of system, I will be interfacing with all sorts of sensors in the sensor module. So, that's all for this lecture. I hope you are quite exposed to this kind of system. You are ready to take up this new challenge which has come to you.

Now, you can replace all. Even NI DACs are not that cheap, okay? So, they are expensive too. So, yes, this also is very, very expensive, but they are IP-certified. They are CE Certified. They have a huge amount of certifications which are there, and they are run by a different class altogether. So, yes my best wishes to you all to come up with your come up with that level so that you can make things which are industrially acceptable. So, do robotics with a better system, which is acceptable. That's all. Thanks a lot for this. Next lecture, we'll be covering actuators after that, sensors that will use all these systems. Thanks a lot