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Servomotor control via Ethernet

Interdisciplinary project

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Contents

List of Figures

1 Theoretical foundations

1.1 Servomechanisms

The term servomechanisms refers to devices that have the ability to sense their output quantity and correct it without external assistance, using a feedback loop with a sensor. Generally, this term is used only for systems in which the mechanical position or its derivatives (speed, acceleration) are controlled by the feedback signal.

In most applications, servomechanisms are used for power amplification, meaning the signal of a low-power device controls a more powerful device. In this way, the operation of the more powerful device is a result of the signal, error, or discrepancy obtained by comparing the actual value with the desired value. The power ratio of the control signal to the power of the controlled device can be up to $1 : 10^9$. [12]

All servomechanisms have at least these basic components: a controller, an actuator, a system or object, and a sensor (shown in figure 1).

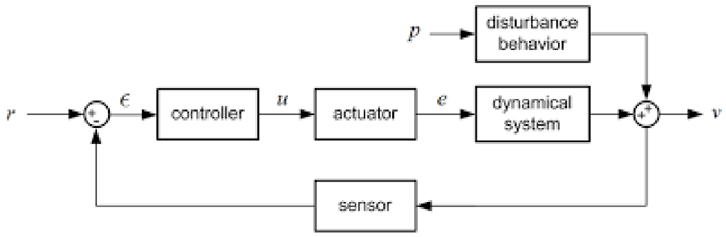

Figure 1: A simple scheme of a servo system

The input signal to the system is the desired value or reference, which is compared to the actual value measured by the sensor. The next value is the error, which serves as the input signal for the controller. The controller can be programmed to function as a proportional, integral, or derivative component, or any combination of these three. The controller then sends a signal to the actuator. The actuator's task is to adjust the required quantity, which in turn modifies the system.

As an example, we can consider a central heating system with a thermostat. The controlled variable is the temperature. In this case, the system is the fire, which is supplied with more or less oxygen for combustion. A disturbance could be, for example, variations in fuel quality. The actuator consists of the flaps that the thermostat opens and closes to regulate the oxygen supply. The controller is the lever and chain on the thermostat, which adjusts the response speed and limit values. The sensor is a tube submerged in water that expands based on temperature. The desired temperature is the input variable, which we set using the rotary knob on the thermostat itself.

Servo systems vary based on:

- the type of motor used:
  - DC (smaller power and lower speeds)
  - AC (higher power and higher speeds)
- the type of feedback loop:
  - Analog (feedback is not a digital signal)
  - Digital (feedback is a digital signal, the controller is a computer)
- the type of movement:
  - Rotational (we control the angle, rotational speed, and angular acceleration)
  - Linear (we control the position, linear speed, and linear acceleration)
- working medium
  - Pneumatical (quicker with lesser forces)
  - Hydraulic (slower with greater forces)

1.2 Servomotor

A servomotor is a servo system that uses either an AC or DC electric motor and is designed for precise motion control. Brushless motors are the most commonly used type of servomotors [10]. They are among the most widely used motor types in automation, robotics, and other applications where a high level of accuracy and repeatability is required. Due to their low inertia, they are capable of high acceleration. However, they are mostly used for lower power applications due to significant energy losses and low efficiency [15].

A servomotor operates based on a feedback loop, meaning it receives information about its current position or speed and uses this data to adjust its operation to achieve the desired outcome. This is accomplished with the help of an integrated sensor, typically a position sensor or an optical encoder [10], which allows the motor to determine how it's moving and where it's located. The servomotor is part of a servomechanism and is used in combination with a servomotor driver [10].

Servomotors are commonly used in applications requiring high speed and precision [10]. In industrial robotics, for example, servomotors control robotic arms that move objects with exceptional accuracy. They are also widely used in modeling, where they control the movement of guides, aircraft control surfaces, and other functions. Additionally, servomotors are frequently employed in mechatronics, the automotive industry, production automation, medical equipment, and other fields. The ability to provide precise and rapid movement [10], along with easy installation and operation, is a key advantage of servomotors.

1.3 Programmable logical controller

A Programmable Logic Controller (PLC) is often described as a miniature industrial computer [13], designed to be robust and tailored for executing control functions [13] in manufacturing processes such as assembly lines, machinery [13], robotic systems, or any application requiring high reliability, easy programming, and process fault diagnosis. PLCs consist of two main components: the central processing unit (CPU) and the input/output interface [13]. They can be expanded with numerous modules, significantly increasing their versatility.

PLCs were initially developed for the automotive industry as flexible, robust, and easily programmable controllers to replace hardwired relay systems [13]. Since then, they have been widely adopted as automation controllers with high reliability, suitable for demanding environments.

We distinguish between fixed (integrated or compact) PLCs and modular PLCs [14]. Fixed PLCs are named as such because they have a predefined number of input and output units [14]. Modular PLCs, on the other hand, offer greater flexibility since various modules can be added, hence the name "modular." This allows for scalability and makes them more adaptable. However, because they are modular, all necessary components must be individually connected to the microcontroller [14].

PLCs can be designed for various configurations of digital and analog inputs and outputs, different temperature ranges, resistance to electrical noise, as well as resistance to vibrations and shocks [13].

Programmable Logic Controllers (PLCs) are an example of a real-time system, as their output states depend on the inputs within a limited time frame. If there are significant time delays, undesired operations or states may occur.

1.4 GX Works 3

GX Works 3 is a software for programming, configuring, and diagnosing various automation systems based on the Mitsubishi Electric platform. It is a powerful tool used for programming industrial controllers, specifically for the MELSEC iQ-R and iQ-F series control systems [9].

The GX Works 3 software is designed for ease of use and supports programming in multiple languages, including standard programming languages for controllers, as listed and defined in the IEC 61131-3 standard [9]. This provides users with flexibility and the ability to choose the most suitable language for their needs. GX Works 3 provides an extensive library of functions, blocks, and algorithms that facilitate the rapid and efficient development of automated solutions. Users can create and modify programs while visually monitoring their applications through an intuitive user interface [9]. Additionally, it supports the integration of various automation system components, such as sensors, drives, and user interfaces, using profiles available in the included library [9] or additional device profiles accessible on their website.

GX Works 3 also supports advanced functionalities such as simulation [9] and diagnostics, which allow for testing and debugging programs before their implementation in the actual system. This reduces maintenance time and costs while increasing the reliability of automation systems. Additionally, it enables version tracking of changes made by multiple authors [9].

In summary, GX Works 3 is a powerful tool for developing automated systems, allowing users to easily and efficiently create, configure, and maintain automation solutions on Mitsubishi Electric platforms.

1.5 MR Configurator 2

MR Configurator 2 is software developed by Mitsubishi Electric for configuring and programming servomotor drivers from their MR series. This software is designed for engineers and technicians involved in automation and servo system management in various industrial applications.

MR Configurator 2 enables users to easily and intuitively configure servo drives. Through its user interface, engineers can set various servo drive parameters such as speed, acceleration, braking, torque, and other essential settings [8]. It also allows for the configuration of communication parameters, including the selection of communication protocols such as Ethernet or RS485 [8].

The MR Configurator 2 software also enables programming and monitoring of servo drives through various operating modes [8]. It supports advanced functions such as automatic tuning [8], which optimizes servo drive performance for a specific application.

Additionally, MR Configurator 2 provides diagnostic and monitoring capabilities for servo drives. Users can track sensor values, drive status, and other critical information in real time [8]. It also enables data collection and analysis of servo drive performance, allowing users to gain a better understanding of the system's operation and improve its efficiency [8].

MR Configurator 2 is a powerful software tool that simplifies the configuration, programming, and monitoring of Mitsubishi Electric servo drives. With its intuitive user experience and extensive range of features, it enables engineers and technicians to efficiently manage servo systems in industrial applications.

2 System composition

In my system (Figure 2), I used the FX5U PLC (Figure 3) from Mitsubishi Electric, the MR-JE-10C servomotor driver (Figure 4), the HG-KN13J servomotor (Figure 5), and the TP Link TL SG108E (Figure 6).

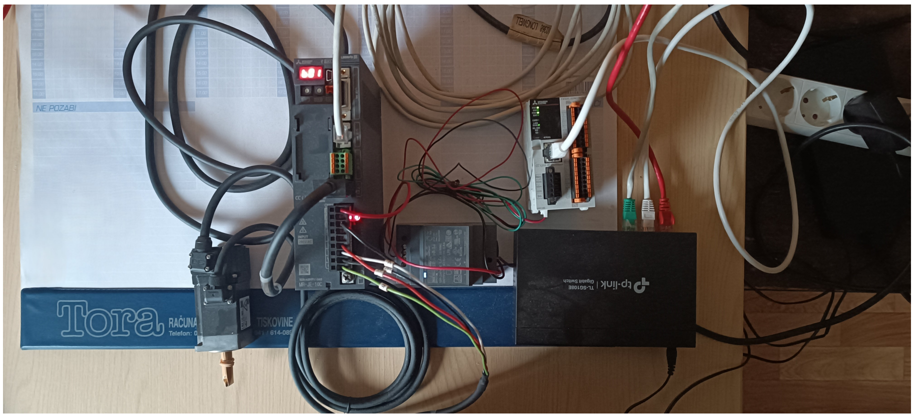

Figure 2: Photo of the wired system

Figure 3: The FX5UC–32MT/DSS–TS PLC

Figure 4: The MR–JE–10C driver

Figure 5: The HG–KN13J servomotor

Figure 6: The TL–SG108E switch

The components listed above are connected as follows: The PLC and the servomotor driver are connected to the network switch via an Ethernet cable, the switch is connected to the computer also using an Ethernet cable. The servomotor is connected to the servomotor driver, according to the schematic in Figure 7, using the supplied cables. The first cable is for the encoder and connects to input CN2 on the driver, while the second cable is for powering the servomotor and is wired according to the schematic.

2.1 PLC FX5UC

The PLC used in my project is the FX5UC–32MT/DSS–TS controller, which is part of the iQ-F product family from Mitsubishi Electric Corp. This product family features an enhanced high-speed BUS connection [3] and represents a comprehensive solution with a built-in power supply, CPU, and I/O interface [3]. The iQ-F family includes the FX5S, FX5UJ, FX5U, and FX5UC

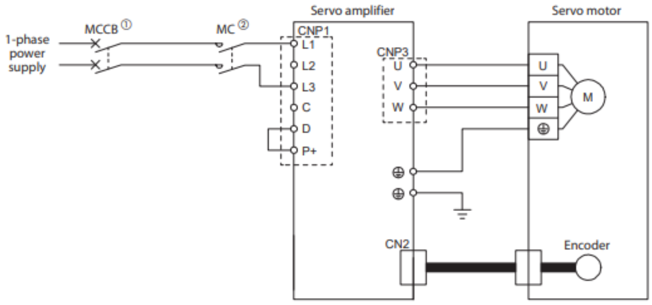

Figure 7: The wiring diagram for the servomotor driver and the servomotor

variants. The PLC I used belongs to the FX5UC series, which includes a built-in SD memory card slot, Ethernet port, RS–485 communication port (e.g., for MODBUS), and an I/O module, making it the most compact PLC in the iQ-F family [5].

This PLC has 16 inputs, which can be set to either a high or low default state, and 16 outputs. It includes a built-in SD memory card slot, an Ethernet port, and an RS–485 communication port (e.g., MODBUS). Additionally, it offers easy expansion with additional modules. It also has strong security functions and battery-free memory, but a battery can be added to increase the amount of stored data [4].

2.2 Servomotor driver MR–JE–10C

Servomotor drivers are components of the so-called motion control system. This concept encompasses various types of motion, including single-axis or multi-axis control [6]. Servo amplifiers are specially designed frequency converters for driving servomotors, enabling dynamically executed movements [6].

The MR–JE–10C servomotor driver is a single-axis driver, meaning it is designed to control only one servomotor. This servomotor driver belongs to the MR–JE series from Mitsubishi Electric Corp. and is suitable for power ratings up to $0.1kW$ [2]. The number 10 in the model name indicates its power rating, while the letter C signifies that this driver includes a built-in Ethernet interface [6].

The MR–JE family of servomotor drivers provides three different control modes for servomotors. It allows control of position, speed, or torque [6]. In position control mode, it enables high precision in reaching the desired position with a high number of pulses per second [6]. In addition to setting the desired position, speed, and torque individually, this driver also allows for defining the maximum speed, acceleration time, and deceleration time [6].

2.3 Servomotor HG–KN13J

The HG–KN13J servomotor is a rotary motion servomotor from the HG–KN series, designed for 200 V AC voltage with a rated power of 0.1 kW. It is a low-inertia servomotor, making it suitable for dynamic movements. It generates a maximum torque of 0.95 Nm and has a maximum rotational speed of 5000 min^{-1}. It provides high precision in reaching the desired position with an absolute encoder that has a resolution of 131 072 $\frac{p}{rev}$ [1]. This motor is suitable for use in assembly machines, label printers, knitting and embroidery machines, as well as ultra-small robots and robotic tips [6].

The naming convention of the servomotor is described in Figure 8, and it tells us that the HG–KN is the servomotor series. The first number indicates the power rating of the servomotor, which in our case is 0.1 kW. The next number tells us that the rated speed of this servomotor is 3000 min^{-1}. The letter J indicates that the motor uses a radial shaft seal.

For this particular servomotor, we could have used MR–JE–10 A, B(F) or C, which was used [7].

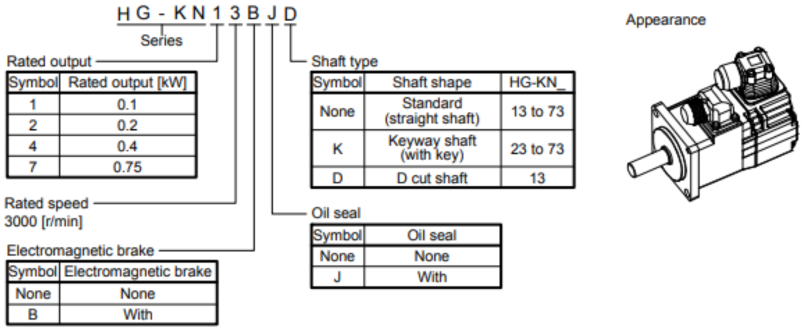

Figure 8: Description of the naming convention of the used servomotor

2.4 TL–SG108E network switch

The TL–SG108E network switch from TP–Link is a switch with eight gigabit ports, capable of automatically routing IPTV traffic to the appropriate port. This means that we can receive both internet and television simultaneously over a single incoming cable without issues [11].

3 Servomotor driver parameters

To set the parameters of the Mitsubishi MR–JE–10C servomotor driver, we need the MR Configurator 2 software and a direct PC-to-driver connection via a USB Mini cable [8]. A number of parameters need to be configured, but the relatively simple user interface is quite helpful in this process.

If we have successfully established a connection with the driver, a new project will automatically open, where all the currently set parameters of the driver will be recorded. If we want to start a new project, we can open it by clicking the "Project" button in the top left corner, and then, in the menu that opens, click "New".

Once the desired project is open, on the left side in the tree structure, click the "Parameter" button [8]. This will open a new window where we will set all the necessary parameters. In the new window, the "Network 1" tab is open by default, where we will set the IP address of the driver. It must be in the same network as the PLC (only the last three digits can differ, e.g., 192.168.3.250 – PLC and 192.168.3.1 – driver). We also specify its network mask and default gateway, which are always set as shown in Figure 9.

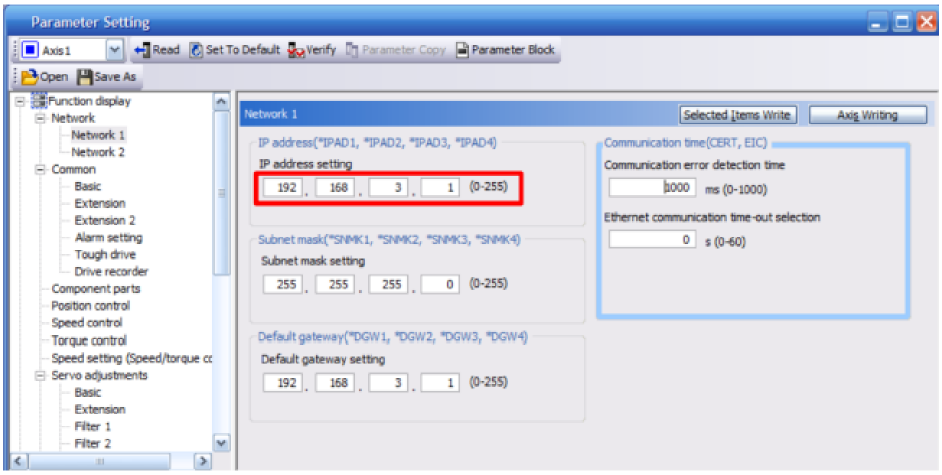

Figure 9: Network 1 settings

Next, we need to click the "Basic" button to open a new tab. In this tab, we set the control mode of the driver to "Profile mode," allowing us to control the servomotor in different profiles (position, speed, torque). We could set it to a specific profile, but then we would only be able to use that one, e.g., the speed profile.

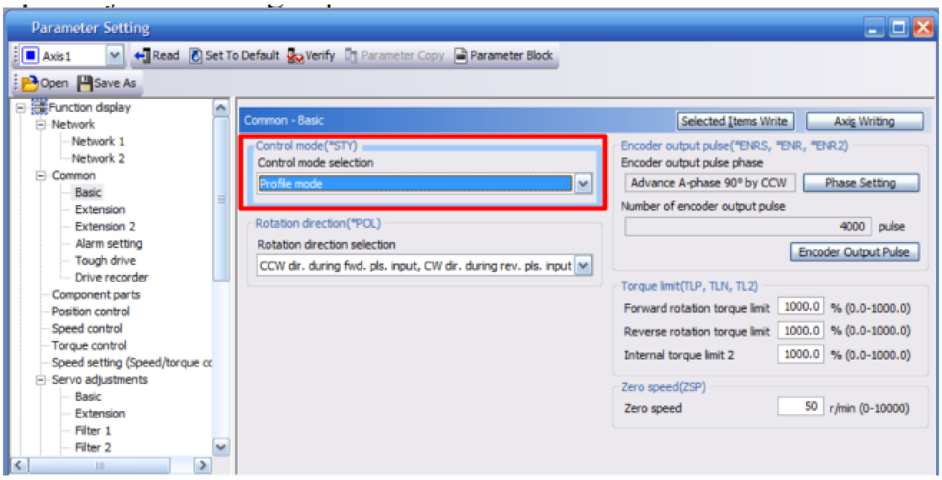

Figure 10: Setting the operating mode of the servomotor

Next, we click the "Extension" button, where we can enable direct testing of the servomotor's operation (Figure 11). If we want to test the operation of the servomotor directly with the MR Configurator 2 program, we must first enable test operation here. However, if we want to control the servomotor through the controller, we MUST disable test operation.

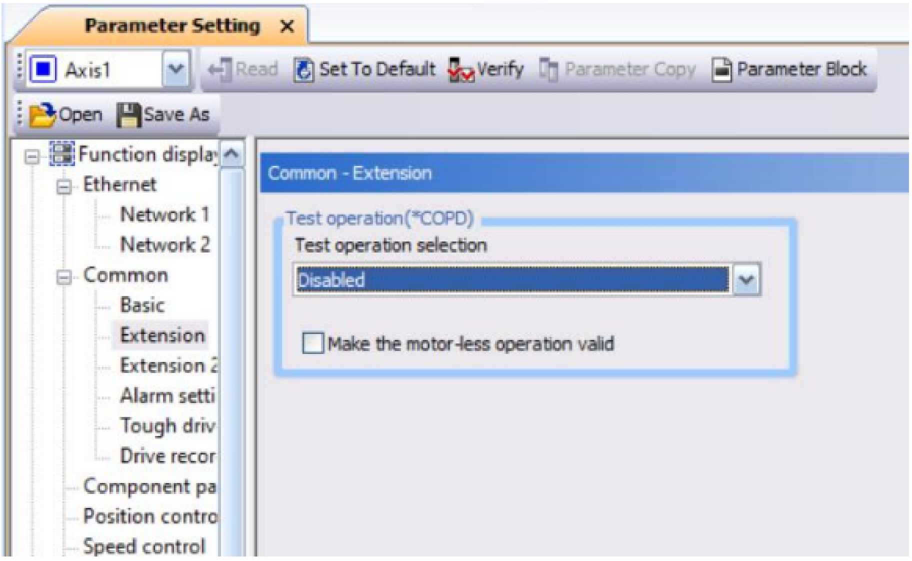

Figure 11: Test operation

Next, we can set the electronic gear. It allows for precise positioning, even if the servomotor has a reducer, for example. To set it, click the "Position Control" button in the tree structure and then, within this tab, click "Electronic Gear," where we can set the desired gear ratio (Figure 12).

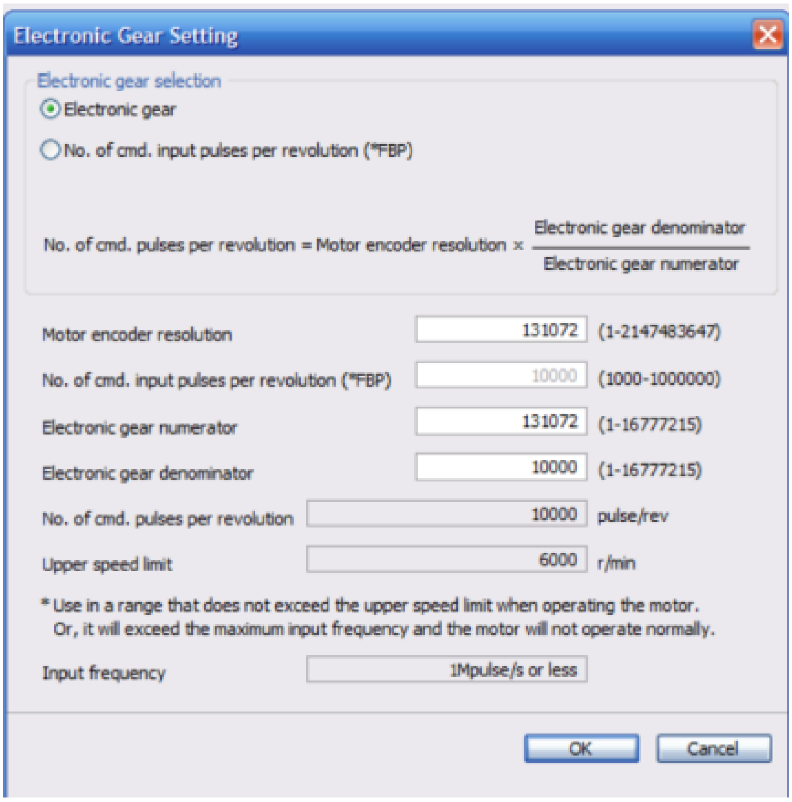

Figure 12: Electronic gear setting

Next, we need to set the method for determining the servomotor's zero position. To do this, we must click on "Home Positioning Return" and within this tab, set the parameters as shown in Figure 13.

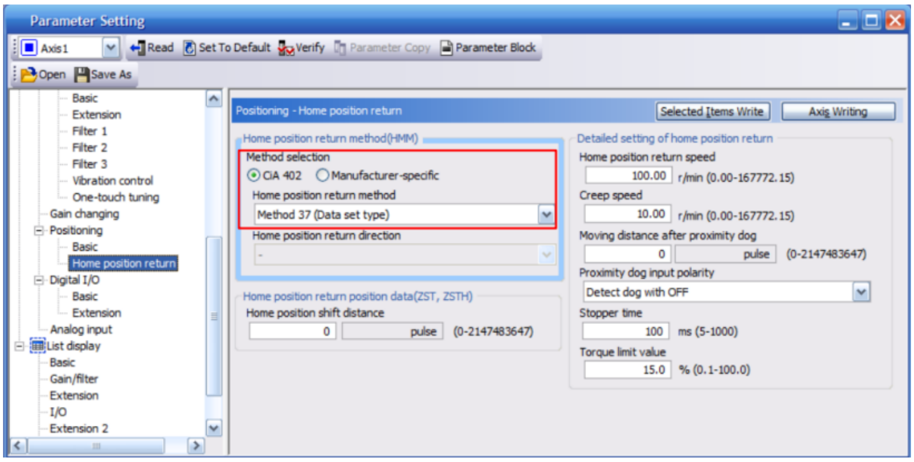

Figure 13: Setting the desired method for determining the zero position

Finally, we need to set the default values for the inputs of the driver. To do this, click the "Digital I/O" button, and on this tab, click "Auto ON" and set the values as shown in Figure 14.

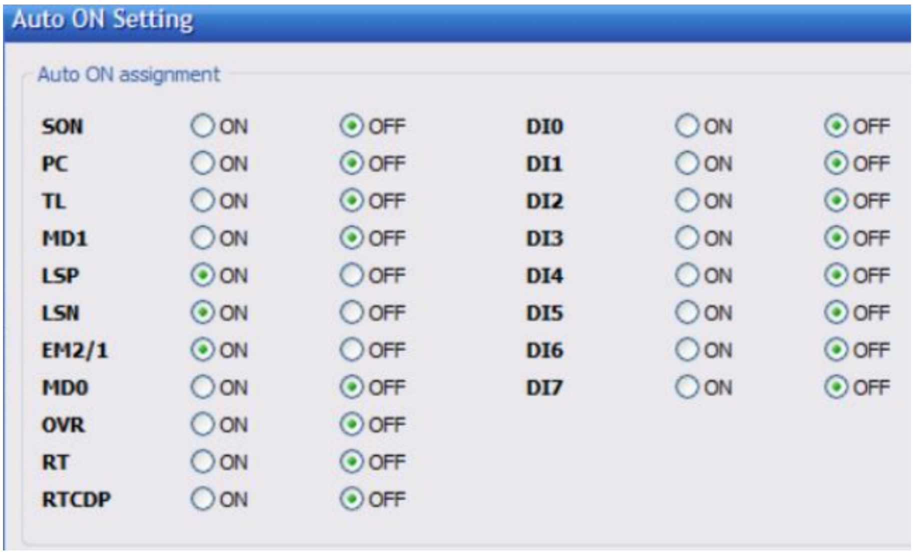

Figure 14: Default input values

Lastly, click the "Axis Write" button at the top right. This will write the configured parameters to the driver, and then you can close MR Configurator 2.

4 PLC - PC connection

To connect the PLC to the computer, we need the GX Works 3 software. In it, we create a new project and specify the type of controller that we will be using. In this case, it is the FX5U (Figure 15).

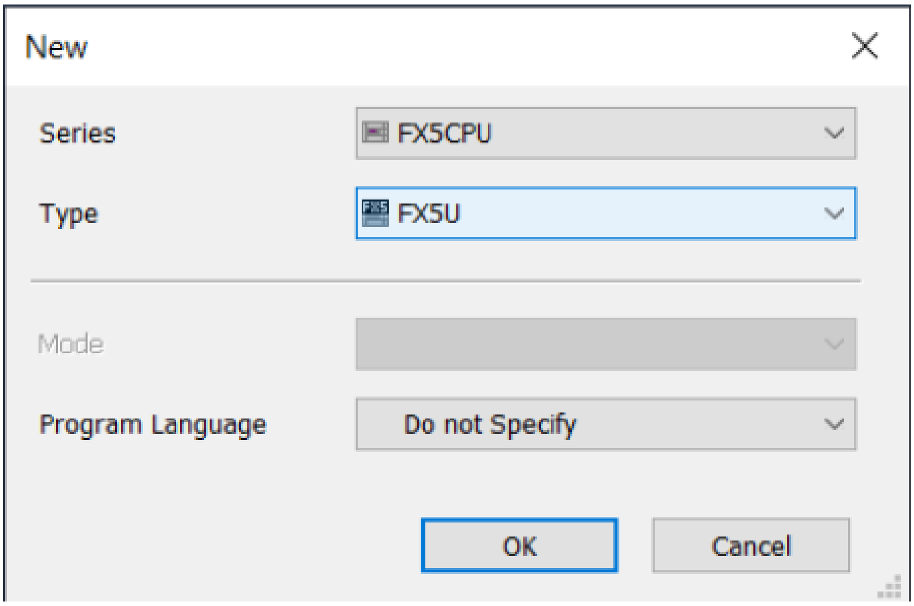

Figure 15: Choosing the PLC

Next, we click the "Online" button located at the top of the screen. A menu will open (shown in Figure 16), where you click the "Current Connection Destination" button.

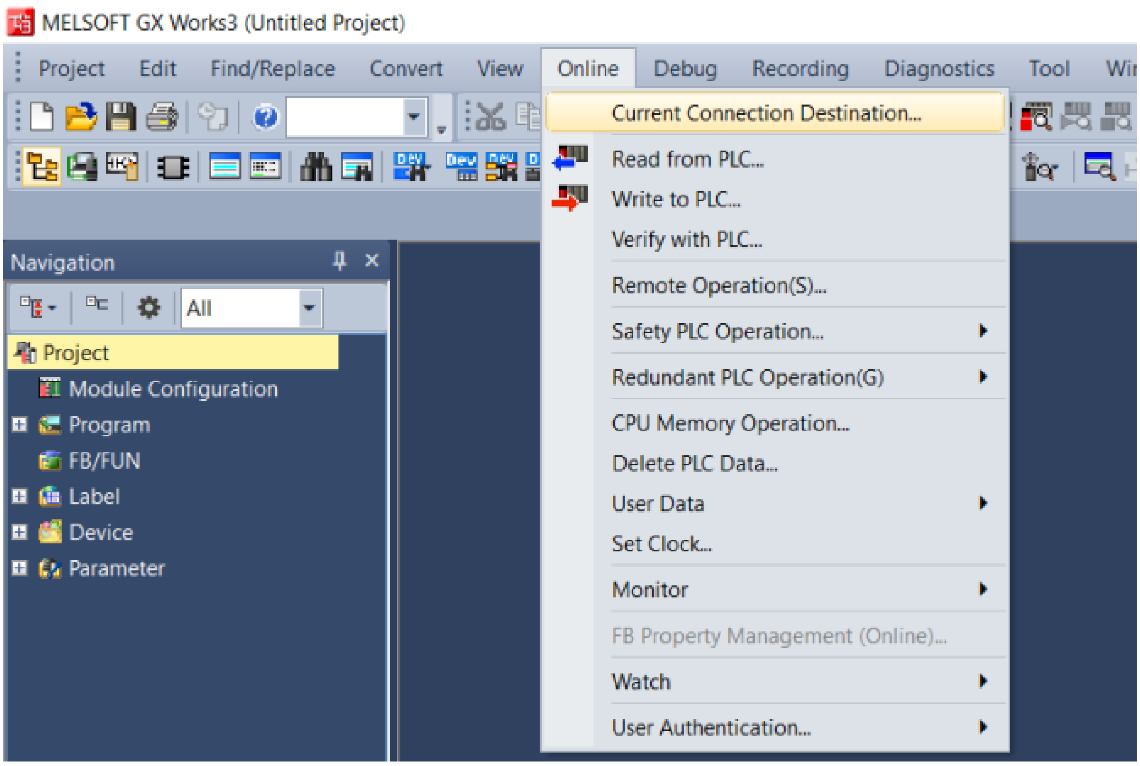

Figure 16: "Online" button menu

A window will appear as shown in Figure 17, where we select the connection method between the PC and the PLC:

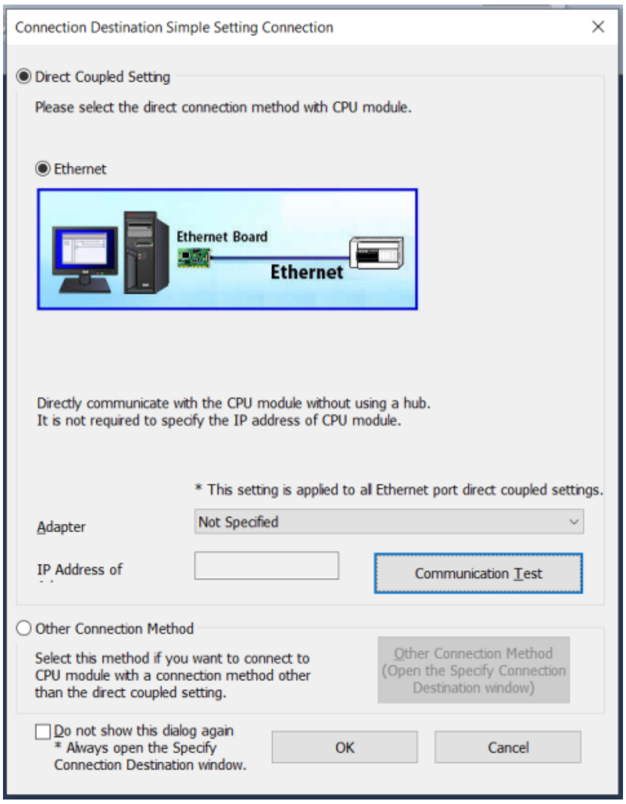

Figure 17: Setting the connection type between the PLC and PC

In our case it is "Direct Coupled Setting". That means that we have a direct cable connection to the PLC, not to an additional Ethernet module.

Next, we specify which computer network card we are using for communication, in my case, the Ethernet network card. It will also display the IP address of our device within the network, which we will return to later. Then, we click the "Communication Test" button, and if everything is done correctly, a window will open displaying: "Successfully connected with the FX5U PLC," which means that the connection to the controller has been successfully established.

To further verify if the communication is established, we can use the "ping" command in the command prompt (cmd), through which we ping the PLC. If the PLC and the PC are connected, something similar to what is shown in Figure 18 will appear.

```
Pinging 192.168.3.250 with 32 bytes of data:
Reply from 192.168.3.250: bytes=32 time<1ms TTL=64
Reply from 192.168.3.250: bytes=32 time<1ms TTL=64
Reply from 192.168.3.250: bytes=32 time=2ms TTL=64
Reply from 192.168.3.250: bytes=32 time<1ms TTL=64

Ping statistics for 192.168.3.250:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 2ms, Average = 0ms
```

Figure 18: Demonstration of the use of the ping command

5 PLC parameters

On the controller, it is necessary to set up everything related to communication and the program used to control the servomotor.

Once the computer and PLC are connected, click the ”Ethernet port” button on the left in the tree structure (highlighted in the figure), and a window will appear as shown in the figure 19.

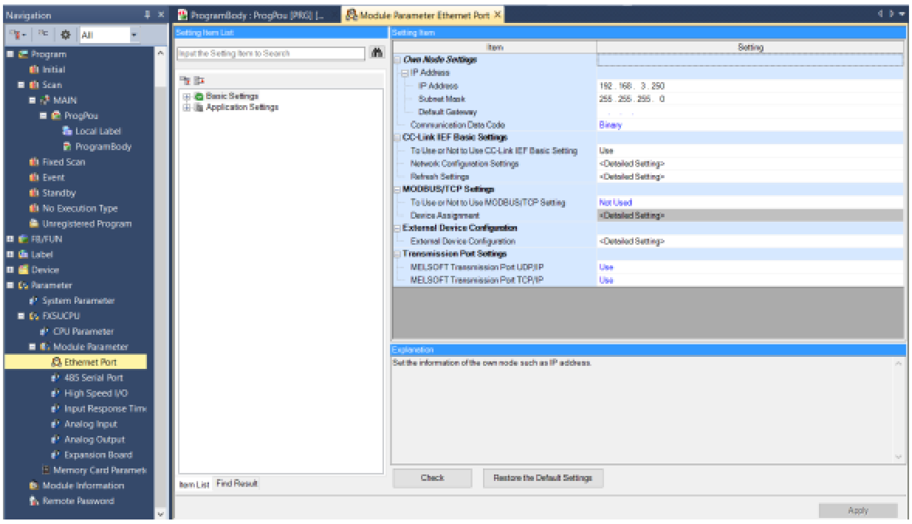

Figure 19: The “Ethernet Port” window

Next, we must set the parameters as seen in the figure 20.

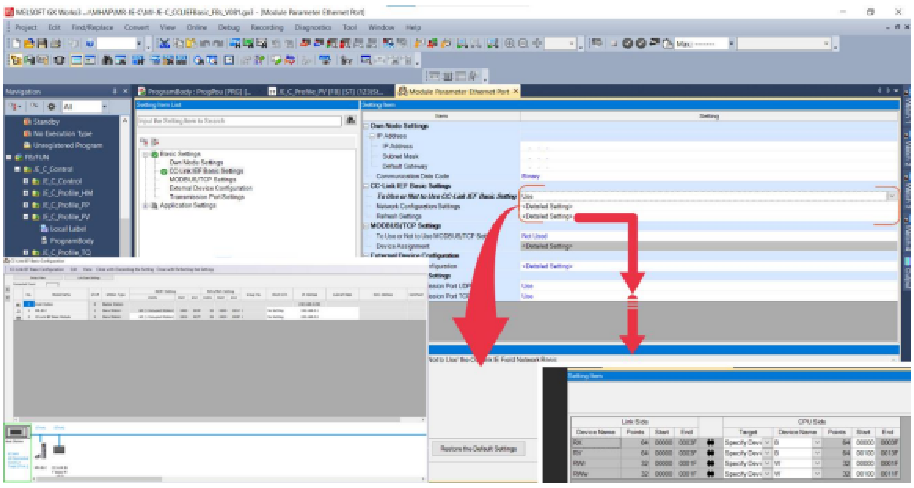

Figure 20: Communication parameters

Lastly, we must set the "External Device Configuration" parameters (found in the "Ethernet Port" window) as seen in figure 21.

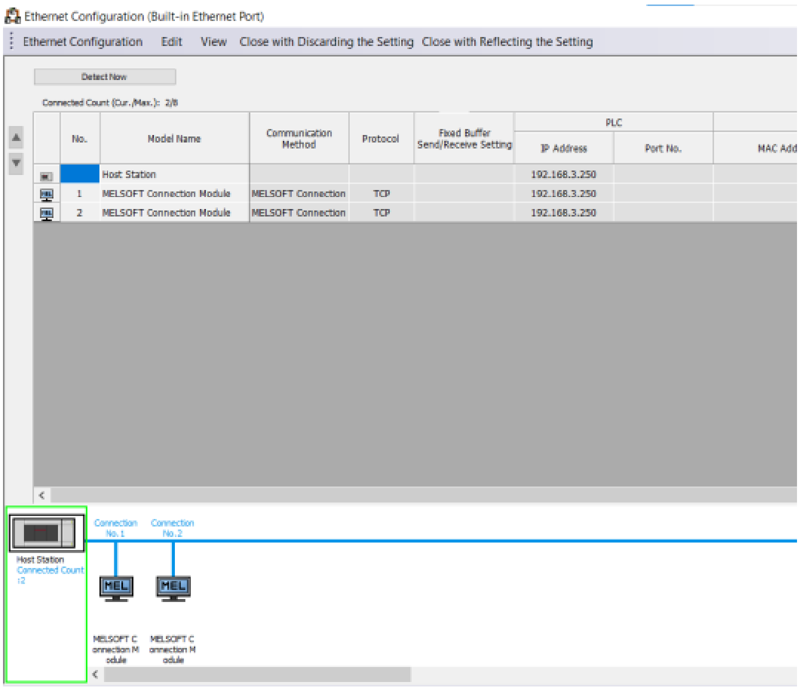

Figure 21: Parameters of connected devices

Finally, we must write all of the parameters we have set to the PLC by clicking the "Online" button and then "Write". The window seen on figure 22 opens. Next, we click "Parameter + Program" or "Select All" and then "Execute".

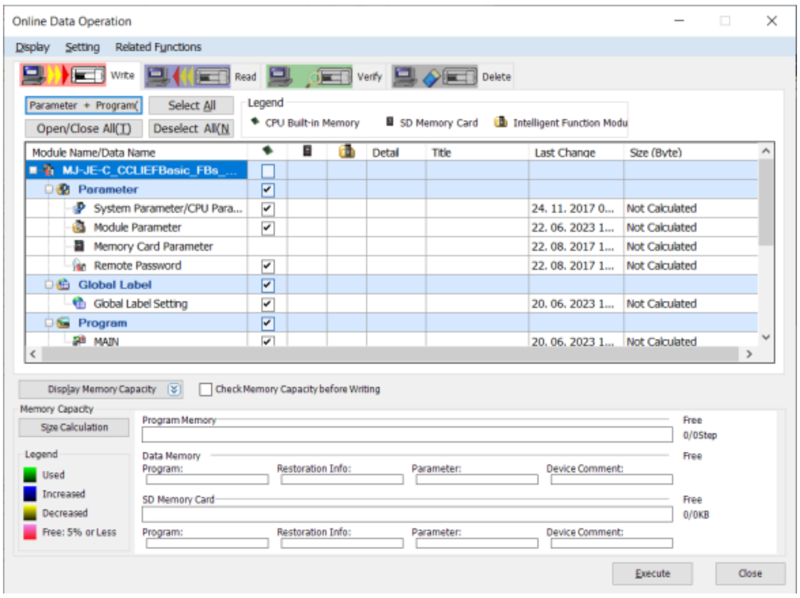

Figure 22: The upload window

6 Program functions

The program for controlling the servomotor was provided by the support team of the Mitsubishi equipment supplier in Slovenia. It includes five blocks that are used for control.

The first block is used for communication and control (figure 23). The first input of this block starts the communication between the controller and the servomotor driver, the second input activates the driver's operation, the third and fourth inputs set the torque limit in percentages, which was defined as 1000%, the fifth input is an emergency stop, the sixth input resets errors, and the last input specifies which axis or servomotor is being controlled.

The first output indicates the communication status, the second output shows the status of the driver, the third output reports the control mode of the servomotor, the fourth output displays the current position, the fifth shows the current speed, the sixth indicates the number of pulses being sent from the driver to the servomotor, the seventh reports the current torque, and the eighth informs us if an error has occurred and, if so, provides the error code.

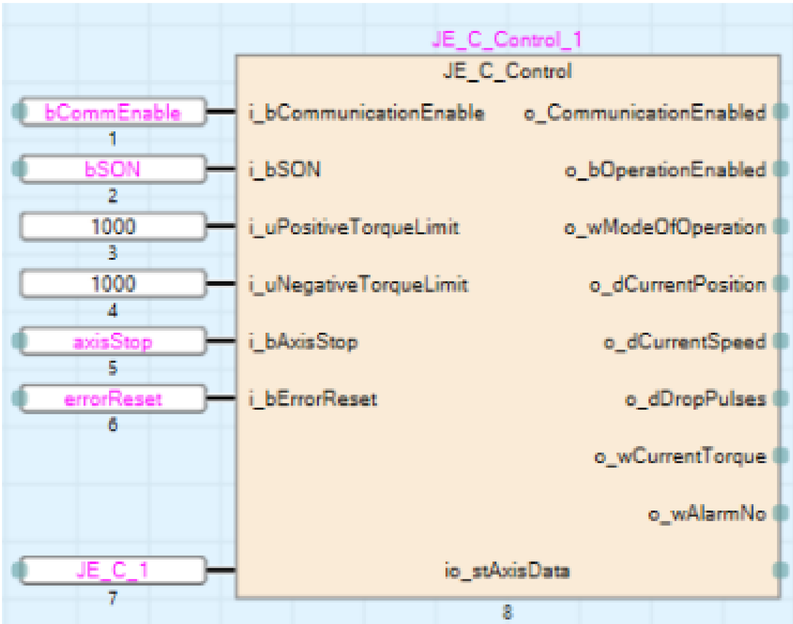

Figure 23: Communication block

The second block (Figure 24) is used for software-based zero position setting. The first input puts the driver into Homing mode, while the second input sets "o_dCurrentPosition" to zero.

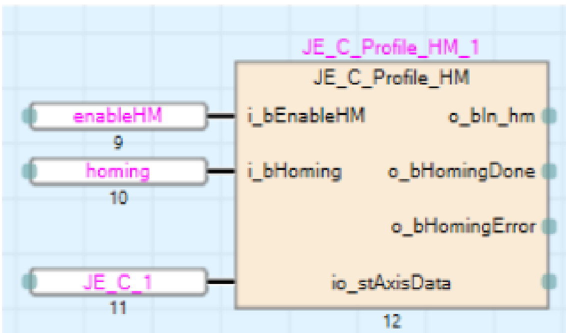

Figure 24: Homing block

The third block (Figure 25) enables position control. The first input switches the driver to position control mode, the second input issues the movement command, the third input sets the acceleration time to the specified speed, the fourth input sets the deceleration time to zero, the fifth input defines the target position for the servomotor's movement, the sixth input sets the maximum movement speed, and the seventh input switches between absolute and relative motion (ON = relative motion).

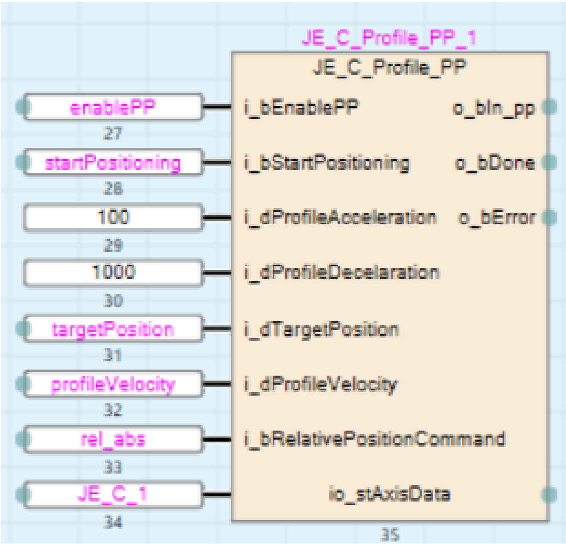

Figure 25: Position control block

The fourth block (Figure 26) enables speed control. The first input switches the driver to speed control mode, the second input issues the movement command, the third input sets the target speed, the fourth input defines the acceleration time to reach the target speed, and the fifth input sets the deceleration time from the target speed down to zero.

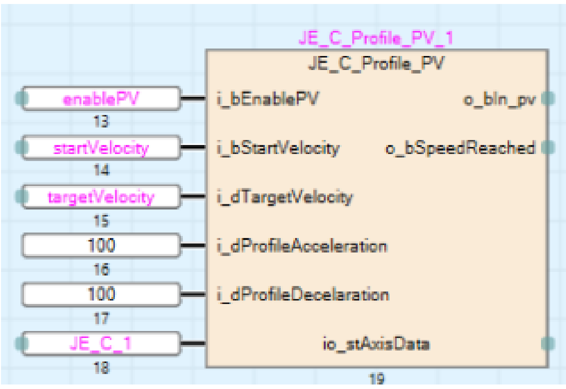

Figure 26: Speed control block

The fifth and final block (Figure 27) allows setting the maximum torque that the servomotor must not exceed. If the torque surpasses this limit, the servomotor stops until the torque returns within the specified range. The first input switches the driver to torque control mode, the second input issues the movement command, the third input sets the maximum allowable torque, the fourth input defines the speed the servomotor can reach, and the fifth input determines the slope at which the torque can increase.

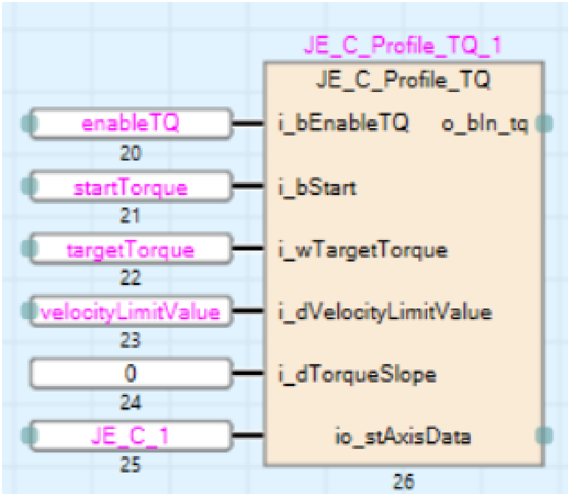

Figure 27: Torque control block

7 Conclusion

The project assignment was very interesting to me, as I learned many new things.

I had the most difficulties at the beginning because I received information that the servo motor could be controlled with a frequency converter. Later, I obtained the correct information, which enabled me to successfully complete the project. In a similar situation in the future, I will try to seek information from responsible persons more quickly. A major problem for me was also establishing communication between the controller and the servo motor driver, as the instructions I initially received from Mitsubishi support were incomplete and did not explain all the necessary aspects. Nevertheless, the support representative helped me immensely, and I am especially grateful to him for that.

In the end, I learned a lot and enjoyed the project.

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