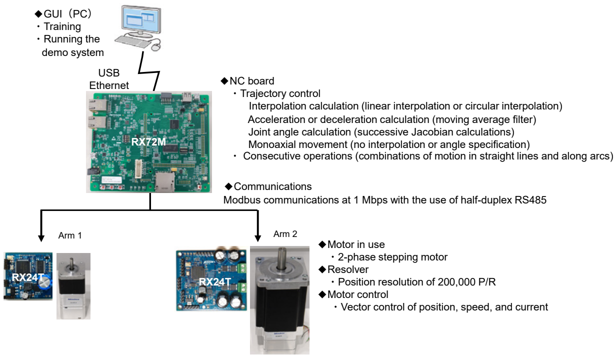
Reference Guide for a 2-Axis Robot Arm with 2-Phase Stepping Motors Incorporating Resolvers

RX24T, RX72M, RAA3064002GFP/RAA3064003GFP

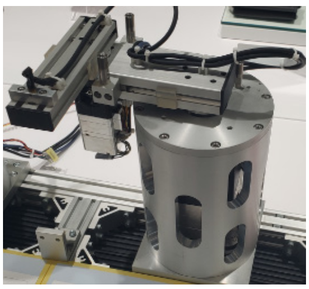
Overview

We have developed a reference kit for a 2-axis robot arm with our solution for positional control involving the use of 2-phase stepping motors incorporating resolvers.
An RX72M handles the numerical control and two RX24Ts handle motor control of the axes. The system enables movement of the arm at speeds of up to 250 mm per second within the movable range of 150 mm x 153 mm.



Features

- Trajectory control of the arm (CP control)
  - Continuous path (CP) control by linear or circular interpolation enables consecutive operations along the path as required (a demonstration video is available on the Renesas website).
  - Arm swing speed is adjustable from low to high (0.017 to 5 r/sec)
  - Motor control for axes: The RX24Ts control the motor positions by using the resolver feedback signals (servo control).
  - System control: The RX72M controls the robot arm as a whole, with each of the segments controlled by an RX24T.
- High positional resolution of 200,000 P/R
  - A positional resolution of 200,000 pulses per revolution is achieved by using 2-phase stepping motors incorporating resolvers manufactured by MinebeaMitsumi Inc. and resolver-to-digital converters (RDC ICs) manufactured by Renesas Electronics.
  - Repeatable positional accuracy: 0.2 mm
  - The positional resolution is 250 times that achievable by open-loop control
- Reducing the reference kit's size by integrating the mechanical and electrical structures
  - Integral structures with the control boards installed at the opposite ends of the stepping motors from the driving ends of the motor axes.
  - Only requiring the power supply and communications lines reduces the amount and complexity of wiring.



- Gearless direct drives
  - Direct drives with high positional resolution eliminate being out-of-step with the resolver positional information and maximize the motor torque.
  - The RX24Ts apply filtering to suppress the mechanical resonances caused by the direct drives.
  - The gearless structure reduces system costs.
- High-speed serial communications
  - Modbus communications at 2 Mbps with the use of half-duplex RS485

Applications

- Service robots
- Small arm robots
- Power-assistance robots
- XY-stage driving
- Automatic guided vehicles
- Electrically driven slides
- Surveillance camera positioning
- Machine tool control
- Textile-related machinery
- Medical equipment
- OA equipment

Introduction

This document is a reference guide for a 2-axis robot arm with 2-phase stepping motors, each incorporating a resolver sensor. The user has to prepare the components of the demo system described in this document. Note that the control board drawings, mechanical part drawings, software for control (for motor control or system control), and a GUI for controlling the demo system, which are listed in Related Documents below, are available for use and can be found on the Renesas Electronics Website.

The demo system can be used for training in movements of the arm tip (written in specific commands) with the use of a GUI on a PC and for moving the arm according to training in continuous path (CP) control by linear or circular interpolation. Refer to the examples of operation posted on the Renesas Electronics Website (URL: https://www.renesas.com/us/en/application/home-building/motor-control-solutions/resolver-motor-control-solutions-consumer-and-industrial-applications#videos).

This document explains the system configuration and mechanical parts of the demo system, circuit diagrams of motor control boards, and methods of manipulating the demo system by using the GUI. For the software to be written to the motor control boards and its control functions, refer to the application note "R01AN5662EJ0100".

Related Documents

- Related to mechanical parts
  Structural drawings of robot arms: R12TU0118

- Related to control boards
  (a) 42-mm square motor control board
    - Circuit drawings: R12TU0106
    - Parts list: R12TU0107
    - PCB pattern drawings: R12TU0108
  (b) 85-mm square motor control board
    - Circuit drawings: R12TU0109
    - Parts list: R12TU0110
    - PCB pattern drawings: R12TU0111
  (c) System control board for NC control (Renesas Starter Kit+ for RX72M (part number: RTK5572MNDS10000BE)
    - User's manual: R20UT4391
  (d) Resolver-to-digital converter
    - User's manual: R03UZ0002

- Related to software
  (a) Software for motor control
    - Application note: R01AN5662EJ0100
  (b) Motor control development support tool "Renesas Motor Workbench"
    - User's manual: R21UZ0004

Related MCUs

- RX24T
- RX72M

List of Abbreviations and Acronyms

Acronym/Abbreviation	Formal Name	Remarks
MCU	Microcontroller	—
Demo system	A 2-axis robot arm using 2-phase stepping motors with resolvers	Not for sale
42-mm square motor	42-mm square 2-phase stepping motor with a resolver	Manufactured by MinebeaMitsumi Inc. Contact MinebeaMitsumi for detailed specifications.
85-mm square motor	85-mm square 2-phase stepping motor with a resolver	Manufactured by MinebeaMitsumi Inc. Contact MinebeaMitsumi for detailed specifications.
42-mm square board	42-mm square motor control board. An RX24T is incorporated as the MCU.	Not for sale
85-mm square board	85-mm square motor control board. An RX24T is incorporated as the MCU.	Not for sale
NC board	System control board for numerical control	NC: Numerical Control The Renesas Starter Kit + for RX72M (part number: RTK5572MNDS10000BE) is used in this demo system.
RMW	Motor control development support tool "Renesas Motor Workbench"	Manufactured by Renesas Electronics Corp.
RDC	Resolver-to-digital converter IC	A resolver-to-digital converter IC (part number: RAA3064002GFP) manufactured by Renesas Electronics Corp. is used on the 42-mm square and 85-mm square boards.
GUI	Graphical user interface	The demo system uses "Demo_Ver1.1", which is a GUI for the 2-axis robot arm.

Contents

1. Specifications of the Demo System

This section describes the overall configuration of the demo system and the specifications of each of the modules.

1.1 Overall Configuration of the Demo System

Figure 1-1 shows the external appearance of the demo system, Figure 1-2 is a system configuration diagram, and Figure 1-3 shows a schematic view of controlling the demo system. Table 1-1 lists the components of the demo system.

The 85-mm square motor is housed in a cylindrical case and connected to arm 1, and the 42-mm square motor and arm 2, which operates in accordance with the rotation of the 42-mm square motor, are connected to the tip of arm 1. A laser module is attached to the tip of arm 2 and the laser light produces illumination in the direction of the ground. The 42-mm square board and 85-mm square board are installed for the 42-mm square motor and 85-mm square motor in respective integral structures, and each of the motors rotates to operate the arms upon receiving control instructions from the NC board, which is connected to the control boards via RS-485 links. Origin sensors for detecting the origin positions of arm 1 and arm 2 are attached to arm 1 and the cylindrical case, and the signals from the origin sensors are connected to the 42-mm square board and 85-mm square board. The system control board is connected to a PC by a USB cable, and control instructions for the motors are generated from operation commands generated with a GUI on the PC. The 42-mm square board and 85-mm square board are driven by a 24-V power supply and the NC board is driven by a 5-V power supply. A 3-V power supply generated on the NC board is supplied to the laser module.

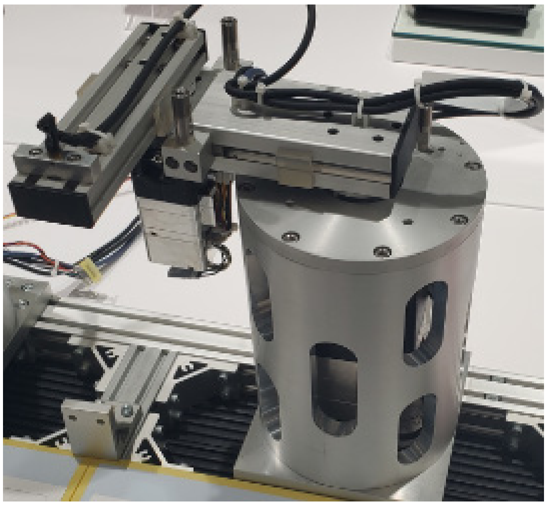


Figure 1-1 External Appearance of the Demo System

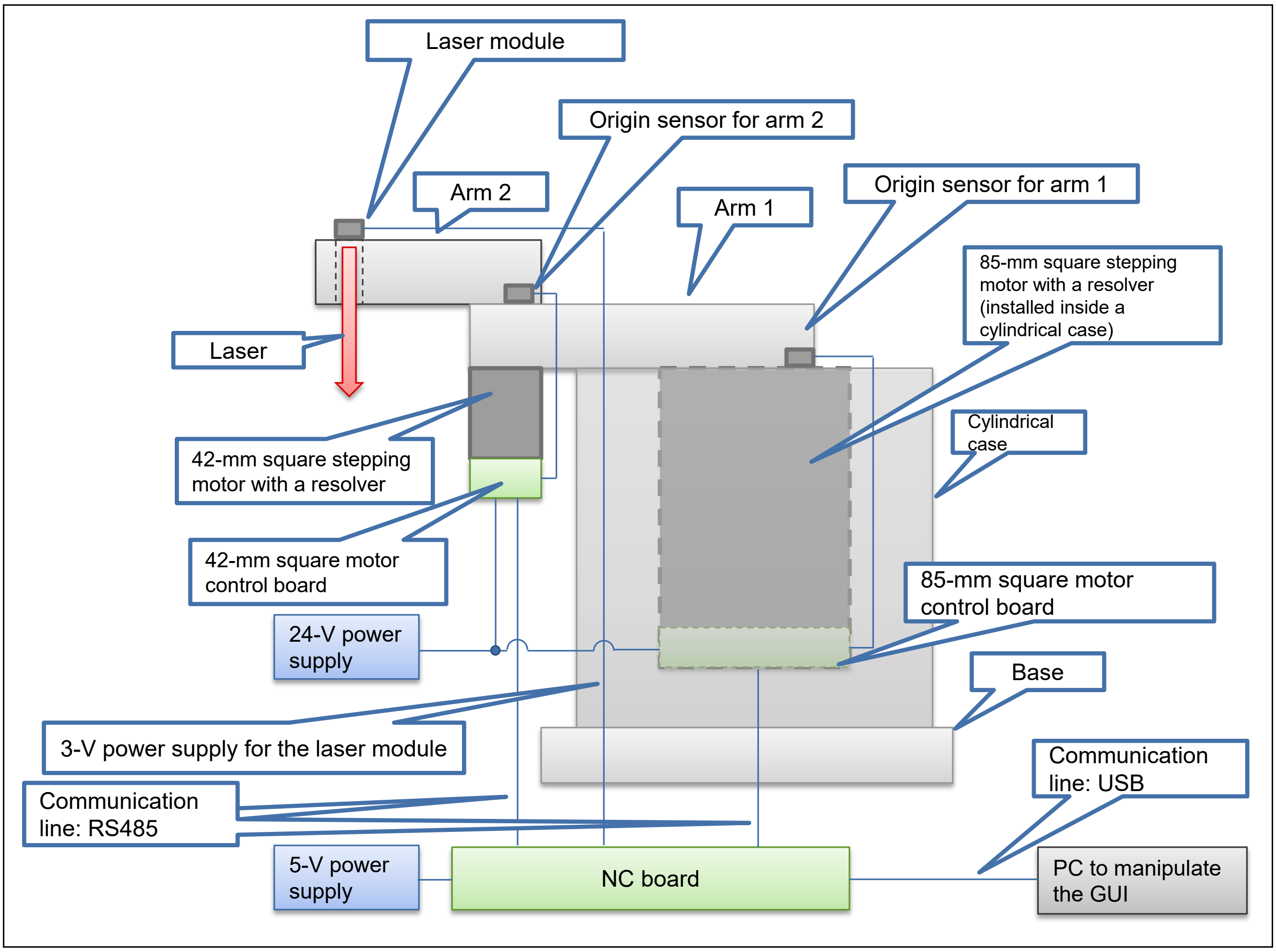


Figure 1-2 System Configuration Diagram

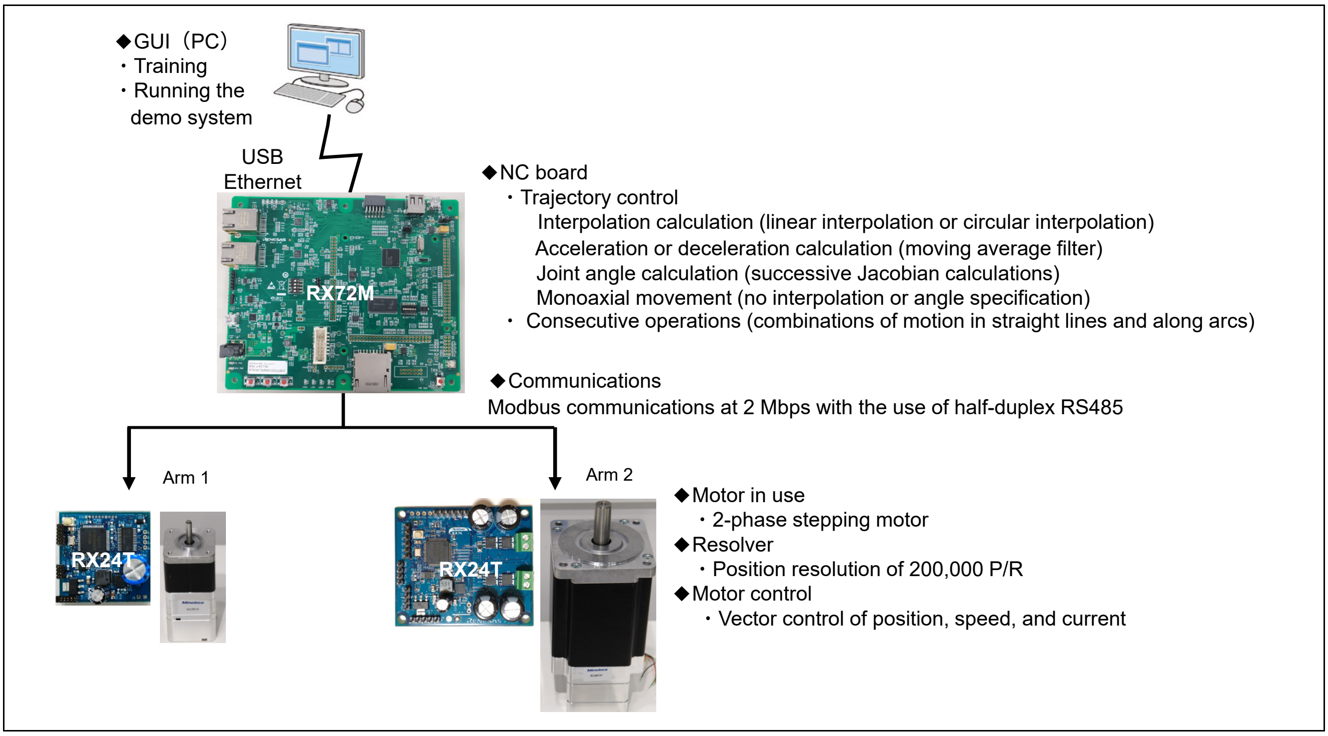


Figure 1-3 Schematic View of Controlling the Demo System

Table 1-1 List of Components of the Demo System (1/2)

Classification	Name	Description	Related Files
Motor control board	42-mm square motor control board	Control board for driving the 42-mm square stepping motor. It is installed at the opposite end of the 42-mm square stepping motor from the driving end of the motor axis. An RX24T and RDC IC are mounted on this control board.	Circuit drawings: R12TU0106 Parts list: R12TU0107 PCB pattern drawings: R12TU0108 Software: RX24T_ROBOT42_STM_RSLV_FOC
	85-mm square motor control board	Control board for driving the 85-mm square stepping motor. It is installed at the opposite end of the 85-mm square stepping motor from the driving end of the motor axis. An RX24T and RDC IC are mounted on this control board.	Circuit drawings: R12TU0109 Parts list: R12TU0110 PCB pattern drawings: R12TU0111 Software: RX24T_ROBOT85_STM_RSLV_FOC
Stepping motor	42-mm square stepping motor with a resolver	42-mm square stepping motor with integrated mechanical and electrical structures (manufactured by MinebeaMitsumi). This motor is used for driving arm 2.	For the model number and detailed specifications, contact MinebeaMitsumi. Contact URL: https://www.minebeamitsumi.com/english/
	85-mm square stepping motor with a resolver	85-mm square stepping motor with integrated mechanical and electrical structures (manufactured by MinebeaMitsumi). This motor is used for driving arm 1.	For the model number and detailed specifications, contact MinebeaMitsumi. Contact URL: https://www.minebeamitsumi.com/english/
System control board	System control board	Used for performing 2-axis CP control. The starter kit for the Renesas microcontroller RX72M is used.	Renesas Starter Kit + for RX72M [RTK5572MNDS10000BE] https://www.renesas.com/us/en/products/microcontrollers-microprocessors/rx-32-bit-performance-efficiency-mcus/rx72m-starter-kit-plus-renesas-starter-kit-rx72m
Mechanical parts	Structural parts for demo system	Structural parts, such as the arms, cylindrical case, base, and origin sensors. The details are given in related files.	Structural drawings: R12TU0118
Power supply	24-V power supply	Power supply for the 42-mm square motor control board and 85-mm square motor control board. Use a power supply unit with the output power of at least 24 V DC/2 A.	—
	5-V power supply	5-V DC power supply for the system control board	—

Table 1-1 List of Components of the Demo System (2/2)

Classification	Name	Description	Related Files
PC	PC for GUI	PC for a GUI used to execute demonstrations. For operating the GUI, the following requirements have to be met in the PC. Supporting OS: 32-bit or 64-bit version of Windows 7, 8.1, and 10 File: .NET Framework 4.7.2 or later	—
	GUI	GUI for training in and operating the demo system	File name: Demo_Ver1.1.exe

1.2 Motor Control Board

1.2.1 Hardware Specifications

Table 1-2 shows the system specifications of the motor control boards. The two motor control boards are the 42-mm square board and 85-mm square board for the motors with the corresponding dimensions. An MCU (64-pin RX24T) and RDC IC, both made by Renesas Electronics, are mounted on both of them, and the 2-phase stepping motors with resolvers can be driven in fast decay mode. Though the RDC IC made by Renesas Electronics has a function for correcting errors in the resolver angle, that function is not used on the 42-mm and 85-mm square boards of this demo system.

For detailed circuit diagrams of each board, see R12TU0106 for the 42-mm square board and R12TU0109 for the 85-mm square board.

Table 1-2 System Specifications of Motor Control Board

Item	Function	42-mm Square Board	85-mm Square Board
Input power supply	Motor power supply	24-V DC	As at left
	Decoupling capacitor	330 uF	400 uF
Internally generated power supply	Gate driver power supply	No (generated within a gate driver)	12 V
	Logic power supply, analog power supply	5 V	As at left
Control microcomputer	MCU part number	R5F524TAADFM (64-pin, 256 KB, Ver. A)	As at left
	Firmware rewriting	The MD/FINED pin is used (single-wire). Note: A 14-pin connector is not mounted.	As at left
Driver	Gate driver	Gate driver with built-in FET (DRV8844 manufactured by Texas Instruments Inc.) Pressure resistance: 60 V Rated current: 1.75 A RMS	UCC27282 manufactured by Texas Instruments Inc. (pressure resistance: 120 V)
			Drive current: 2.5 A
	Driver FET		SQJB90EP manufactured by Vishay Intertechnology, Inc. (pressure resistance: 80 V)
			Rated current: 30 A
Interface	Communication	RMW, pulse string, RS485	As at left
	Servocontrol	No	As at left
	Sensor	Resolver (RDC IC is installed, part number: RAA3064002GFP), origin sensor (DOG, FLS, or RLS)	As at left
Motor control	Gate drive system	Fast decay	As at left
	Current detection	2-phase source current is amplified by the RDC's internal amplifier.	As at left
Protection function	Overcurrent sensing	Detected in the power supply current. When overcurrent is detected, the PWM output is stopped (POE).	As at left
	Gate driver	Thermal shutdown or overcurrent	No
	Hardware reset	Pressing the reset switch returns the system to the initial state.	As at left

(1) Functional block diagram of 42-mm square board

Figure 1-4 shows a functional block diagram of the 42-mm square board.

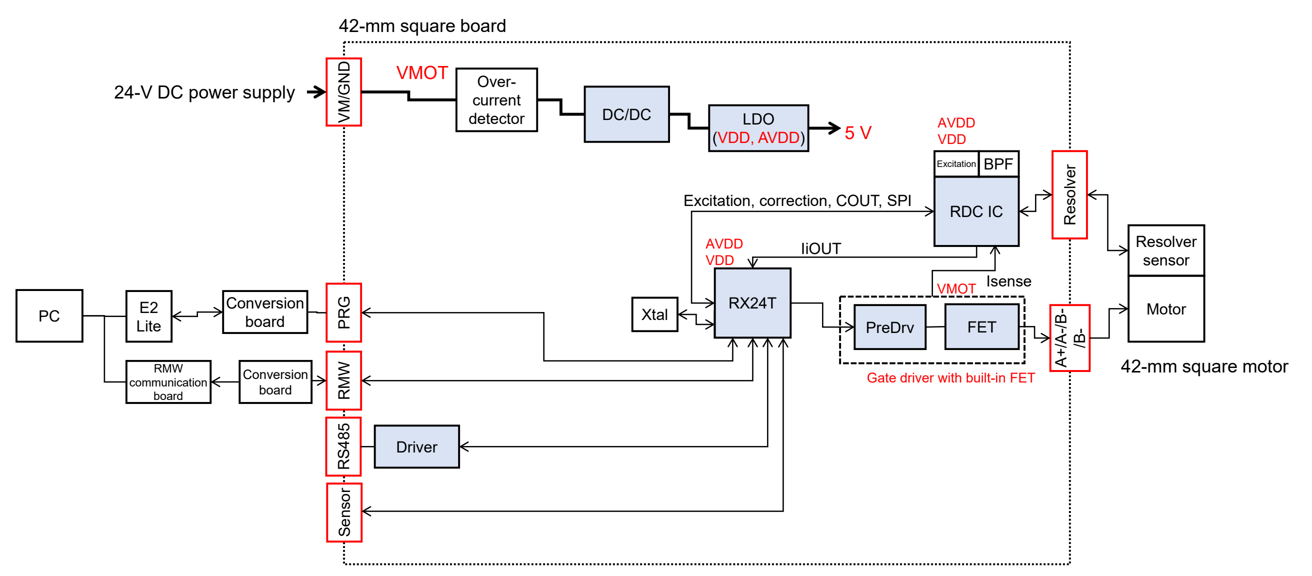
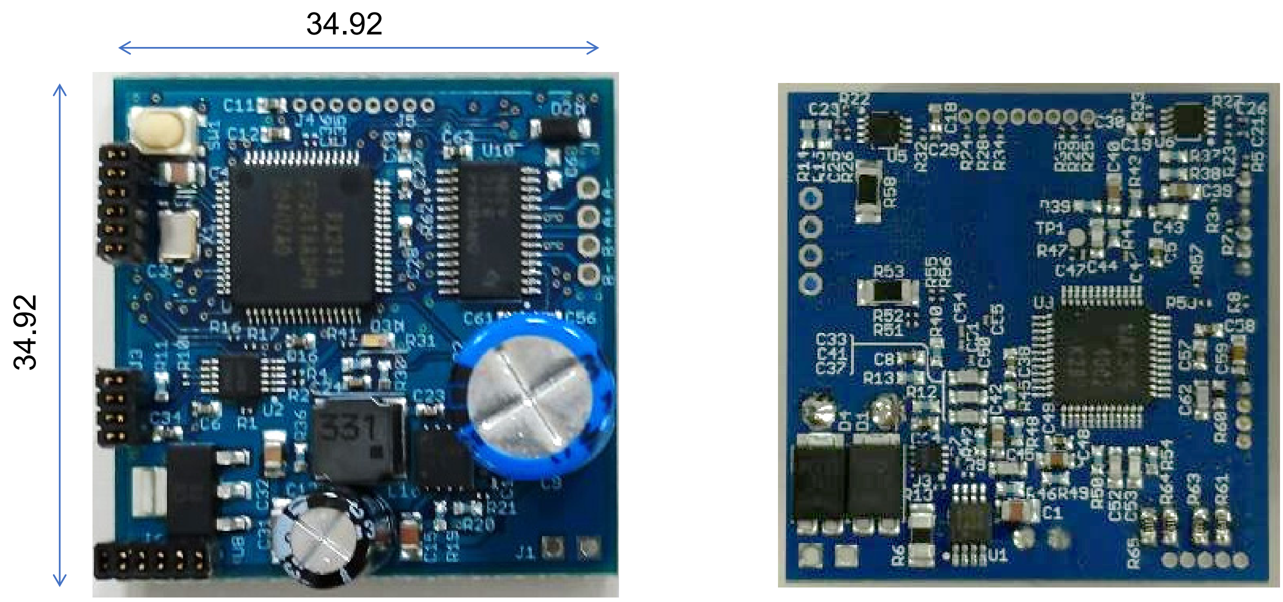


Figure 1-4 Functional Block Diagram of 42-mm Square Board

(2) External appearance of 42-mm square board

Figure 1-5 shows the external appearance of the 42-mm square board.



Top

Bottom (view from solder side)

Figure 1-5 External Appearance of 42-mm Square Board

(3) Component layout of 42-mm square board

Figure 1-6 shows a component layout diagram of the 42-mm square board. Table 1-3 lists the interface connector specifications of the 42-mm square board.

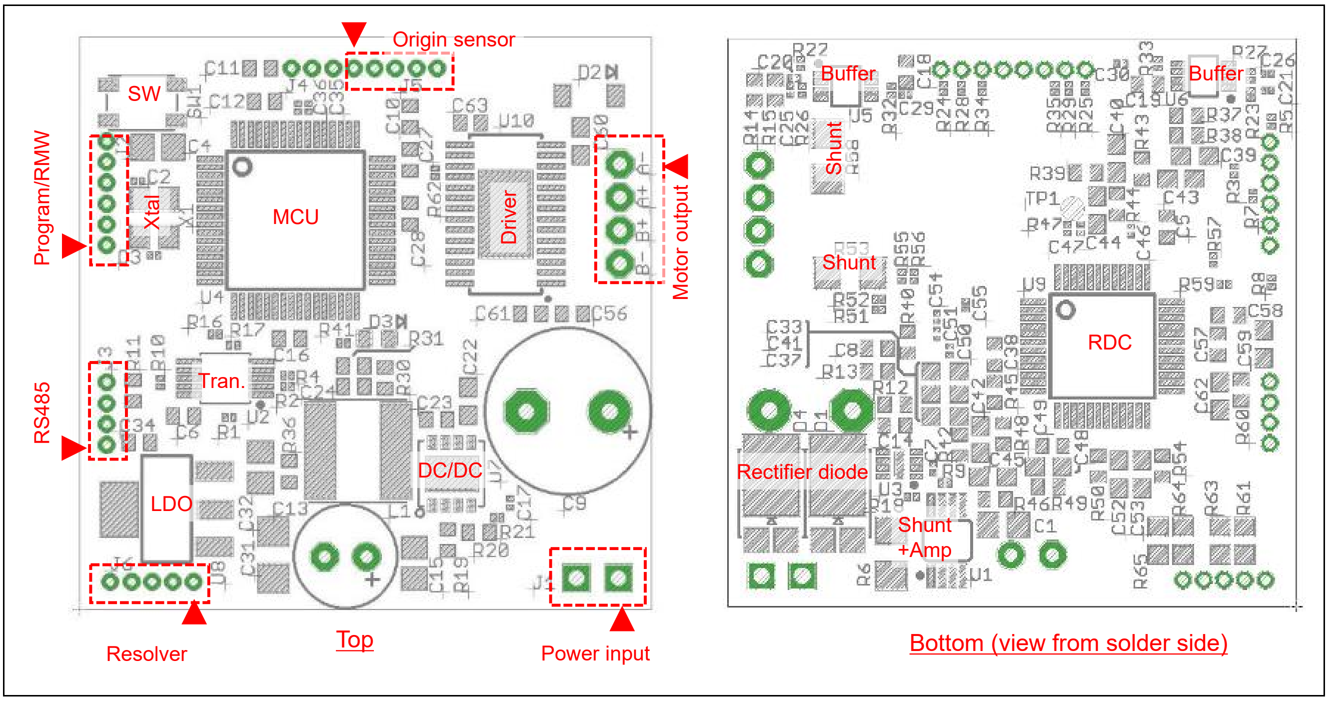


Figure 1-6 Component Layout Diagram of 42-mm Square Board

Table 1-3 Interface Connector Specifications (42-mm Square Board)

Item	Function	Pin (in ascending order of pin number from pin 1)	Connector Shape
Power source	Power input	GND, V+	2.54-mm pitch, 2-pin
Motor	Motor output	A-, A+, B+, B-	2.0-mm pitch, 4-pin
Communication	Program (E1 or E2 Lite)	GND, RX, TX, +5V, MD/FINED, RES#	1.27-mm pitch, 6-pin
	RMW	GND, RX, TX, +5V (pins are used in common with the above program)	1.27-mm pitch, 4-pin
	RS485	GND, B/Z, A/Y, NC	1.27-mm pitch, 4-pin
Sensor	Resolver	XBN, XBP, XAP, XAN, EXC	1.27-mm pitch, 5-pin
	Origin sensor	GND, +5V, RLS, FLS, DOG	1.27-mm pitch, 5-pin

(4) MCU pin assignment of 42-mm square board

Table 1-4 shows the MCU pin assignment of the 42-mm square board.

Table 1-4 MCU Pin Assignment (42-mm Square Board) (1/2)

Pin No.	Pin Name	I/O	Function of Connected Signal	Connection Destination
1	MTIOC9D	O	RDC I/F (CARRIER signal)	RDC
5	IRQ4	I	MCU_FLS	Sensor
12	SSLA1	O	RDC I/F (CS# signal)	RDC
13	TMO1	O	RDC I/F (CLK signal)	RDC
14	PD5	O	RDC I/F (RESET# signal)	RDC
15	PD4	O	UART I/F (RE# signal)	RS485
16	TMO0	O	RDC I/F (PWMINA signal)	RDC
17	RXD5	I	UART I/F (RX signal)	RMW
18	TXD5	O	UART I/F (TX signal)	RMW
19	IRQ3	I	RDC I/F (ALARM# signal)	RDC
20	RSPCKA	O	RDC I/F (SCLK signal)	RDC
21	TXD6	O	UART I/F (DI signal of RS485 transceiver)	RS485
22	RXD6	I	UART I/F (RO signal of RS485 transceiver)	RS485
24	POE4#	I	Overcurrent signal	Overcurrent sensing
26	—	—	—	—
27	MTIOC7A	I	RDC I/F (COUT signal)	RDC
28	P93	O	UART I/F (DE signal)	RS485
29	P92	O	LED	LED
30	MTIOC7C	O	RDC I/F (CC signal)	RDC
31	P90	O	nRESET	Gate driver
33	MTIOC4C	O	Motor gate drive PWM B+L	Gate driver
34	MTIOC3D	O	Motor gate drive PWM A+L	Gate driver
35	P73	O	PWM_EN	Gate driver
36	MTIOC4A	O	Motor gate drive PWM B+H	Gate driver
37	MTIOC3B	O	Motor gate drive PWM A+H	Gate driver
38	IRQ5	I	MCU_CLR	Higher-layer device
40	MTCLKC	I	MCU_PULSE	Higher-layer device
42	MTCLKD	I	MCU_DIR	Higher-layer device
43	TMO6	O	RDC I/F (PWMINB signal)	RDC
44	MOSIA	O	RDC I/F (SDI signal)	RDC
45	MISOA	I	RDC I/F (SDO signal)	RDC
46	MTIOC9A	O	RDC I/F (CARRIER signal)	RDC
49	IRQ2	I	nFault	Gate driver
50	IRQ1	I	MCU_RLS	Higher-layer device
51	IRQ0	I	MCU_DOG	Sensor
52	AN207	I	Power-supply voltage detection	Voltage detecting circuit
53	AN206	I	MNTOUT	RDC
55	—	—	—	—

Table 1-4 MCU Pin Assignment (42-mm Square Board) (2/2)

Pin No.	Pin Name	I/O	Function of Connected Signal	Connection Destination
55	AN101	I	Motor current detection B	RDC
56	AN100	I	Motor current detection A	RDC

(5) Functional block diagram of 85-mm square board

Figure 1-7 shows a functional block diagram of the 85-mm square board.

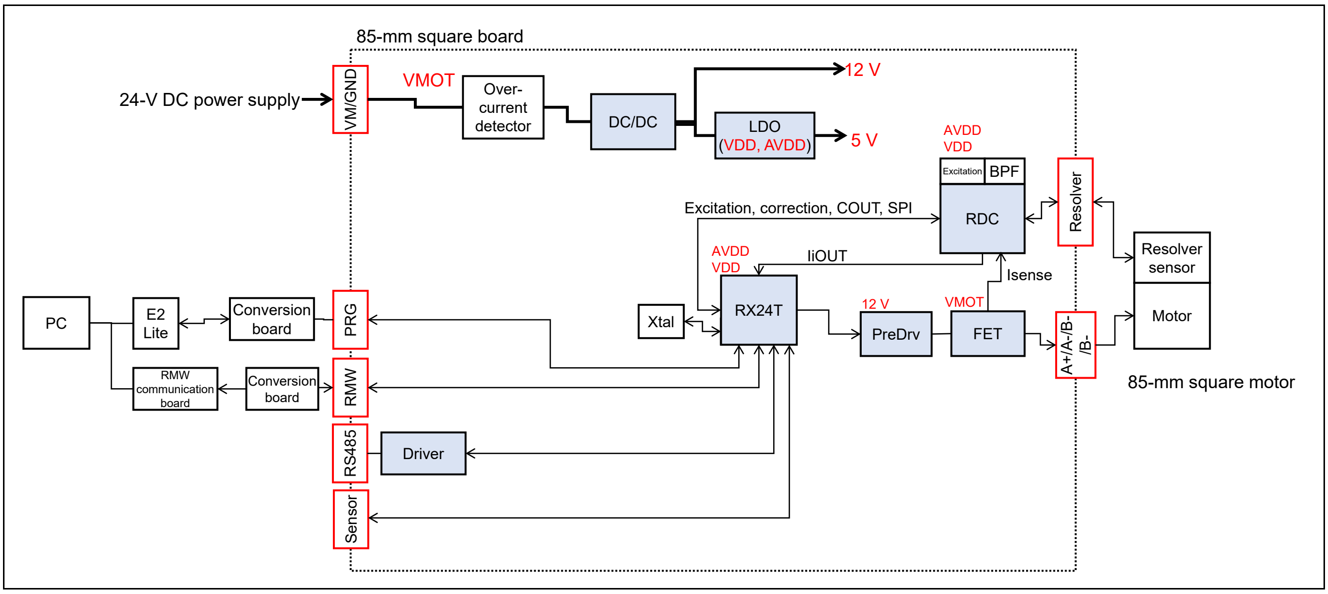


Figure 1-7 Functional Block Diagram of 85-mm Square Board

(6) External appearance of 85-mm square board

Figure 1-8 shows the external appearance of the 85-mm square board.

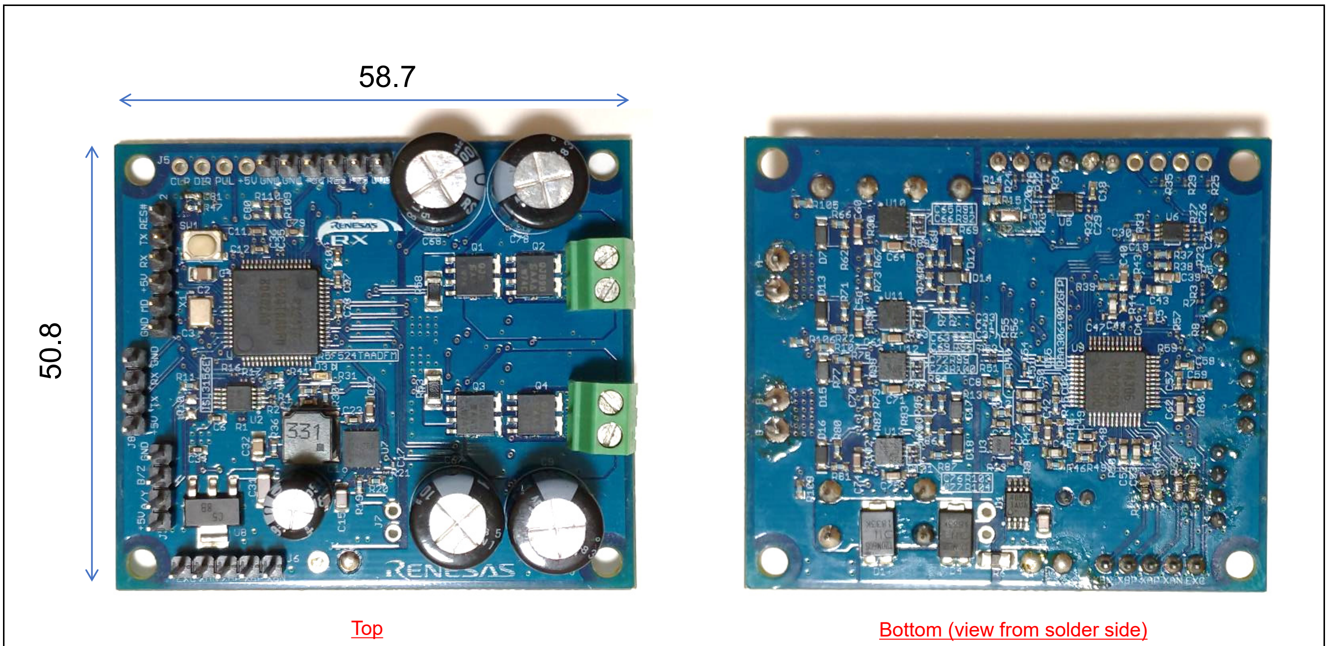


Figure 1-8 External Appearance of 85-mm Square Board

(7) Component layout of 85-mm square board

Figure 1-9 shows a component layout diagram of the 85-mm square board. Table 1-5 lists the interface connector specifications of the 85-mm square board.

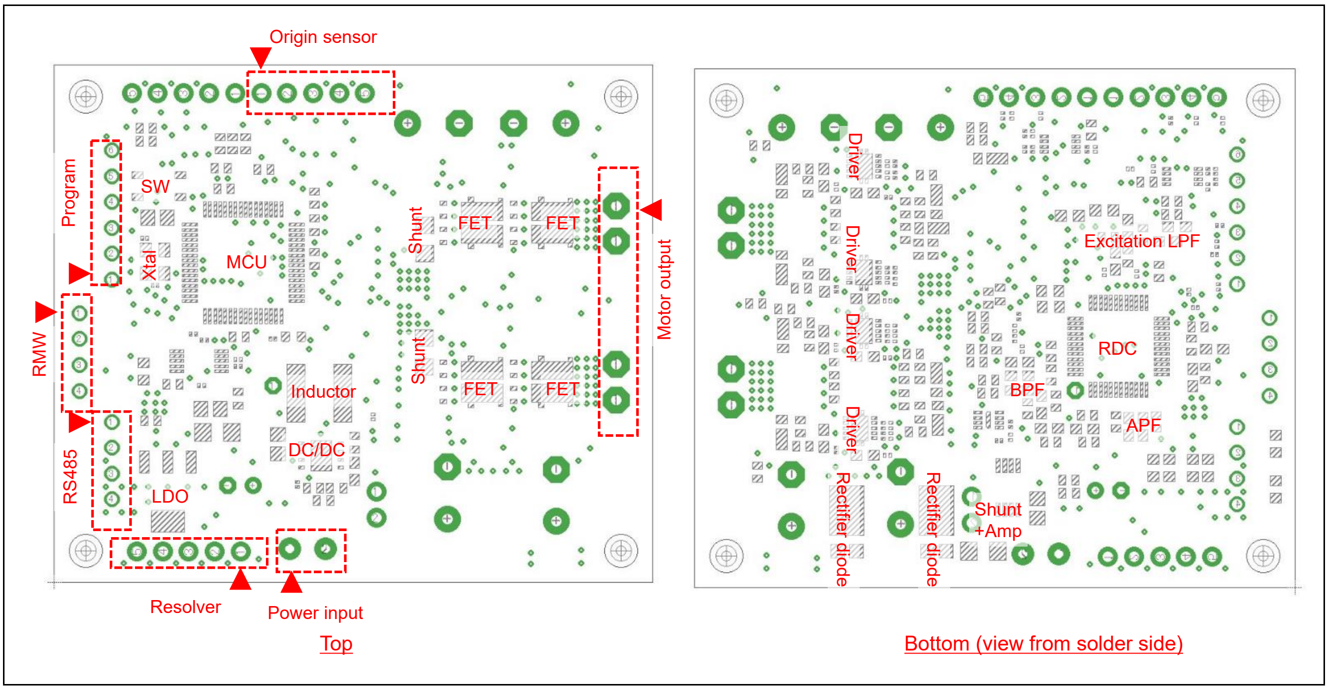


Figure 1-9 Component Layout Diagram of 85-mm Square Board

Table 1-5 Interface Connector Specifications (85-mm Square Board)

Item	Function	Pin (in ascending order of pin number from pin 1)	Connector Shape
Power source	Power input	GND, V+	3.5-mm pitch, 2-pin
Motor	Motor output	A-, A+, B+, B-	ϕ1 mm $\times$ 4
Communication	Program (E1 or E2 Lite)	GND, RX, TX, +5V, MD/FINED, RES#	2.54-mm pitch, 6-pin
	RMW	GND, RX, TX, +5V	2.54-mm pitch, 4-pin
	RS485	GND, B/Z, A/Y, +5V	2.54-mm pitch, 4-pin
Sensor	Resolver	XBN, XBP, XAP, XAN, EXC	2.54-mm pitch, 5-pin
	Origin sensor	GND, +5V, RLS, FLS, DOG	2.54-mm pitch, 5-pin

(8) MCU pin assignment of 85-mm square board

Table 1-6 shows the MCU pin assignment of the 85-mm square board.

Table 1-6 MCU Pin Assignment (85-mm Square Board) (1/2)

Pin No.	Pin Name	I/O	Function of Connected Signal	Connection Destination
1	MTIOC9D	O	RDC I/F (CARRIER signal)	RDC
5	IRQ4	I	MCU_FLS	Sensor
12	SSLA1	O	RDC I/F (CS# signal)	RDC
13	TMO1	O	RDC I/F (CLK signal)	RDC
14	PD5	O	RDC I/F (RESET# signal)	RDC
15	PD4	O	UART I/F (RE# signal)	RS485
16	TMO0	O	RDC I/F (PWMINA signal)	RDC
17	RXD5	I	UART I/F (RX signal)	RMW
18	TXD5	O	UART I/F (TX signal)	RMW
19	IRQ3	I	RDC I/F (ALARM# signal)	RDC
20	RSPCKA	O	RDC I/F (SCLK signal)	RDC
21	TXD6	O	UART I/F (DI signal of RS485 transceiver)	RS485
22	RXD6	I	UART I/F (RO signal of RS485 transceiver)	RS485
24	POE4#	I	Overcurrent signal	Overcurrent sensing
26	—	—	—	—
27	MTIOC7A	I	RDC I/F (COUT signal)	RDC
28	P93	O	UART I/F (DE signal)	RS485
29	P92	O	LED	LED
30	MTIOC7C	O	RDC I/F (CC signal)	RDC
31	—	—	—	—
33	MTIOC4C	O	Motor gate drive PWM B+L	Gate driver
34	MTIOC3D	O	Motor gate drive PWM A+L	Gate driver
35	—	—	—	—
36	MTIOC4A	O	Motor gate drive PWM B+H	Gate driver
37	MTIOC3B	O	Motor gate drive PWM A+H	Gate driver
38	IRQ5	I	MCU_CLR	Higher-layer device
40	MTCLKC	I	MCU_PULSE	Higher-layer device
42	MTCLKD	I	MCU_DIR	Higher-layer device
43	TMO6	O	RDC I/F (PWMINB signal)	RDC
44	MOSIA	O	RDC I/F (SDI signal)	RDC
45	MISOA	I	RDC I/F (SDO signal)	RDC
46	MTIOC9A	O	RDC I/F (CARRIER signal)	RDC
49	—	—	—	—
50	IRQ1	I	MCU_RLS	Higher-layer device
51	IRQ0	I	MCU_DOG	Sensor
52	AN207	I	Power-supply voltage detection	Voltage detecting circuit
53	AN206	I	MNTOUT_DC	RDC
54	AN102	I	MNTOUT_AC	RDC

Table 1-6 MCU Pin Assignment (85-mm Square Board) (2/2)

Pin No.	Pin Name	I/O	Function of Connected Signal	Connection Destination
55	AN101	I	Motor current detection B	RDC
56	AN100	I	Motor current detection A	RDC

1.2.2 Software Specifications

Figure 1-10 shows a functional block diagram of vector control of a 2-phase stepping motor with a resolver used for driving the robot arm, which is used for writing to each of the MCUs (on the 42-mm square board and 85-mm square board) of the demo system. Control of the positions of the motors is based on the resolver feedback signals and position references from the NC board.

For details on algorithms for controlling the motors and the software configuration, refer to the application note "R01AN5662EJ0100".

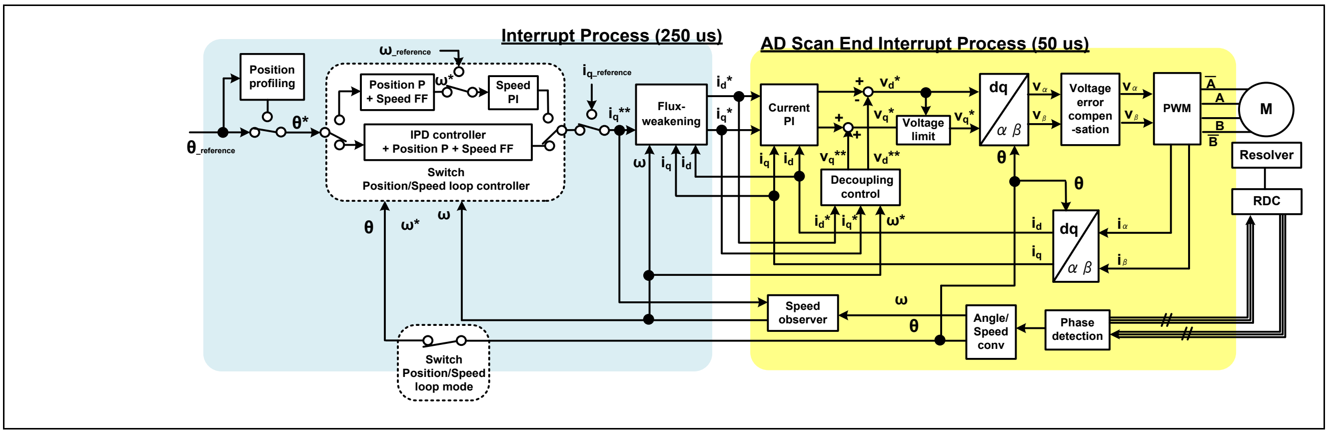


Figure 1-10 Vector Control of a 2-Phase Stepping Motor with a Resolver

1.3 NC Board

Figure 1-11 shows the external appearance of the NC board. The Renesas Starter Kit + for RX72M (part number: RTK5572MNDS10000BE) is used as the NC board of this demo system and the MCU is RX72M. The PC and NC board are connected via a USB cable, CP control is handled upon receiving operation instructions from a GUI running on the PC, and position references of the motor are sent to the 42-mm square board and 85-mm square board which are connected via RS485. The laser module is connected to PMOD2 and the DC3V power is supplied. Note that DC5V is necessary for the power supply of the NC board.

For details on hardware specifications and the method for writing by software, see *Renesas Starter Kit + for RX72M User's Manual*.

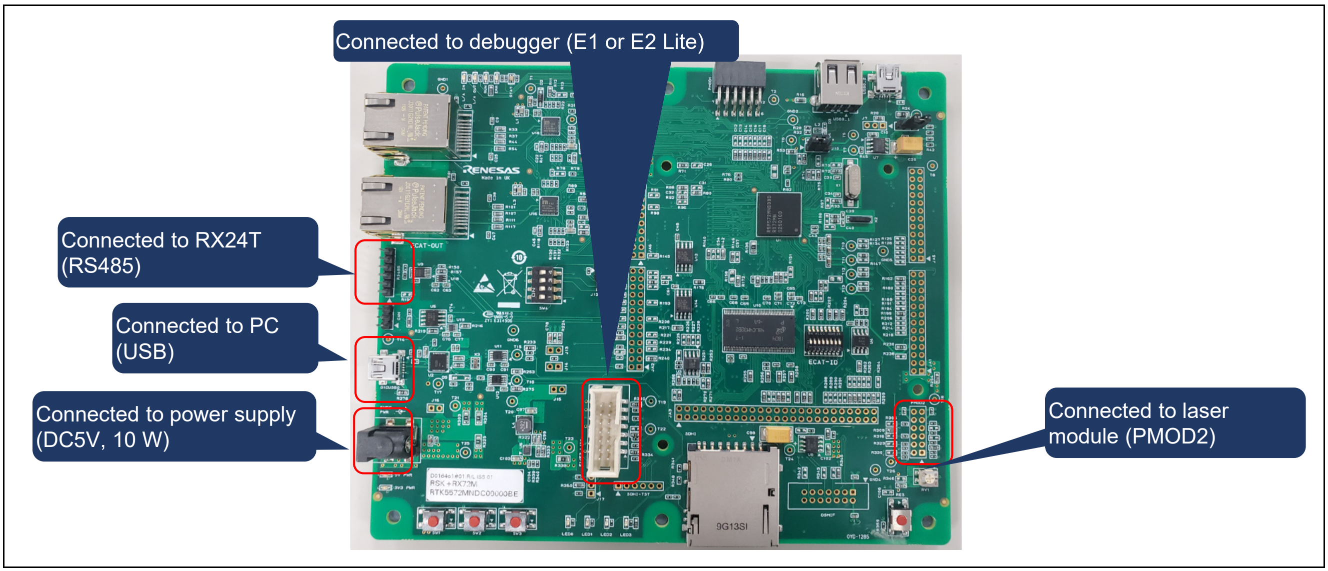


Figure 1-11 External Appearance of NC Board

1.4 Stepping Motors

Figure 1-12 shows the external appearance of the 42-mm square motor and Figure 1-13 shows the external appearance of the 85-mm square motor. Each motor is configured with a control board installed on the opposite end of the driving end of the motor axis. The 42-mm square board is installed for the 42-mm square motor and the 85-mm square board is installed for the 85-mm square motor. Each of the motors and boards are connected to the motor power line and resolver lines. See figure 1-16 in section 1.7 for the wiring.

Table 1-7 lists the main specifications of the motors.

Note that both of these motors are 2-phase stepping motors incorporating resolvers that have been provided by MinebeaMitsumi Inc. Contact MinebeaMitsumi for detailed specifications.

Figure 1-12 42-mm Square Motor

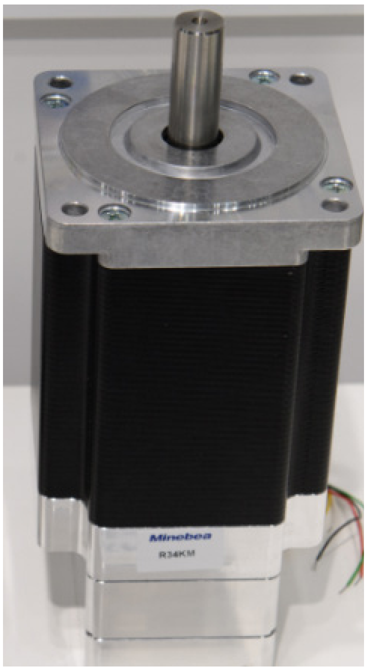


Figure 1-13 85-mm Square Motor

Table 1-7 Main Motor Specifications

Item	42-mm Square Motor	85-mm Square Motor
Rated voltage [V]	24	24
Rated current [A]	2	3
Holding torque [Nm]	0.5 @ 2A	4.4 @ 1A
Phase resistance [Ω]	1.3	1.7
Phase inductance [mH]	2.6	16.6
Inductive voltage [V]	12.1 @ 750 r/min	29.7 @ 150 r/min
Inertia [kgm2]	7.5 × 10-6	370 × 10-6

1.5 Mechanical Parts

Table 1-8 lists the component parts of the demo system. For the drawings of mechanical processed products, refer to *Structural drawings of robot arms (R12TU0118)*.

Table 1-8 List of Component Parts of the Demo System (1)

No.	Model Number (Figure No.)	Product Name	Manufacturer	Required Quantity	Description
1	RE00MT	BASE	Mechanical processed product (created based on drawings)	1	Base
2	RE00MV	COVER_rev1	Mechanical processed product (created based on drawings)	1	Cylindrical case
3	85-mm square MOTOR ASS'Y	85-mm square mechanically and electrically integrated motor	MinebeaMitsumi	1	Integral structure with an 85-mm square board installed for the 85-mm square motor
4	RE00MU	BASE_PLATE	Mechanical processed product (created based on drawings)	1	Lid of cylindrical case
5	RE00MR	LOAD_SHAFT	Mechanical processed product (created based on drawings)	1	Part for installing the 85-mm square motor and arm 1
6	RE00MQ	ARM_1	Mechanical processed product (created based on drawings)	1	Arm 1
7	42-mm square MOTOR ASS'Y	42-mm square mechanically and electrically integrated motor	MinebeaMitsumi	1	Integral structure with a 42-mm square board installed for the 42-mm square motor
8	RE00MP	LOAD_SHAFT	Mechanical processed product (created based on drawings)	1	Part for installing the 42-mm square motor and arm 2
9	RE00MK	ARM_2_Rev0	Mechanical processed product (created based on drawings)	1	Arm 2
10	RE00NQ	BLOCK	Mechanical processed product (created based on drawings)	1	Part for fixing the laser module
11	FU650AD5-C6	Red dot laser module	Akizuki Denshi Tsusho Co., Ltd.	1	Red dot laser module, 1 mW, driven by 3 V
12	RE00LH	STOPPER_1	Mechanical processed product (created based on drawings)	2	Part for fixing the stopper for preventing arm rotation

Table 1-8 List of Component Parts of the Demo System (2)

No.	Model Number (Figure No.)	Product Name	Manufacturer	Required Quantity	Description
13	SETGRS10-30-SC5	Circular post - one end threaded and one end tapped	MISUMI Group Inc.	4	Stopper for preventing arm rotation
14	RE00NE	DOG_1	Mechanical processed product (created based on drawings)	1	Part for detection in the origin sensor for arm 1
15	RE00LM	DOG_2	Mechanical processed product (created based on drawings)	1	Part for detection in the origin sensor for arm 2
16	EE_SX772A	Photomicrosensor	OMRON Corporation	1	Origin sensor for arm 1
17	EE_SX672R	Photomicrosensor	OMRON Corporation	1	Origin sensor for arm 2
18	HFC5_3060_B	Frame cap for aluminum extrusion	MISUMI Group Inc.	2	Frame cap for arm 1
19	HFC5_2040_B	Frame cap for aluminum extrusion	MISUMI Group Inc.	2	Frame cap for arm 2
20	SCB6-20	Hex socket head cap screw - stainless steel	MISUMI Group Inc.	4	M6 × 20 mm
21	SCB5-16	Hex socket head cap screw - stainless steel	MISUMI Group Inc.	16	M5 × 16 mm
22	SHNTP6-4	Post-assembly insertion spring nut for 30-mm or 60-mm square aluminum extrusion	MISUMI Group Inc.	4	Part for fixing the stopper for preventing arm rotation
23	SCB4-20	Hex socket head cap screw - stainless steel	MISUMI Group Inc.	4	M4 × 20 mm
24	SCB3-25	Hex socket head cap screw - stainless steel	MISUMI Group Inc.	8	M3 × 25 mm
25	SCB3-20	Hex socket head cap screw - stainless steel	MISUMI Group Inc.	4	M3 × 20 mm
26	SCB3-10	Hex socket head cap screw - stainless steel	MISUMI Group Inc.	3	M3 × 10 mm
27	SCB3-8	Hex socket head cap screw - stainless steel	MISUMI Group Inc.	3	M3 × 8 mm
28	SCB3-6	Hex socket head cap screw - stainless steel	MISUMI Group Inc.	6	M3 × 6 mm
29	SCB3-5	Hex socket head cap screw - stainless steel	MISUMI Group Inc.	4	M3 × 5 mm

Table 1-8 List of Component Parts of the Demo System (3)

No.	Model Number (Figure No.)	Product Name	Manufacturer	Required Quantity	Description
30	MSSF3-3	Hex socket set screw - flat end	MISUMI Group Inc.	1	M3 × 3 mm locking screw
31	SHNTU5-3	Pre-assembly insertion spring nut for 20-mm, 25-mm, or 40-mm square aluminum extrusion	MISUMI Group Inc.	2	Part for fixing the laser module

Table 1-9 lists the mechanical specifications of this demo system. A movable range of ±90° is enabled by the combination of arms 1 and 2. The swing speed of each arm is in a one-to-one relationship with the rotation speed of the motor because each combination of arm and motor forms a gearless direct drive. Though the software controlling the motor can adjust the maximum swing speed and thus further increase it, the speed is restricted for safety reasons.

The inertia values shown in Table 1-9 need to be set for the 42-mm and 85-mm square boards, respectively, by the software controlling the motors.

Table 1-9 Mechanical Specifications of the Demo System

Item	Value
Size (width × depth × height) Note: Maximum movable range of an arm	Approximately 150 mm × 153 mm × 300 mm
Weight	10 kg
Maximum swing speed of an arm	Arm 1: 10.5 [rad/s] Arm 2: 31.4 [rad/s]
Maximum movable range of an arm	±90°
Inertia from the 85-mm square motor	12 × 10-3 [kgm^2]
Inertia from the 42-mm square motor	0.735 × 10-3 [kgm^2]

1.6 GUI

"Demo_Ver1.1.exe", which is a GUI for this demo system operates on a PC without having to be installed. The necessary conditions for running on a PC are as follows:

- Supporting OS: Windows 7 (32-bit or 64-bit version), Windows 8.1 (32-bit or 64-bit version), and Windows 10 (32-bit or 64-bit version)
- Required file: .NET Framework 4.7.2 or later

Store the GUI file in any folder of the PC and double-click on the GUI icon (see Figure 1-14) to start the GUI (see Figure 1-15).

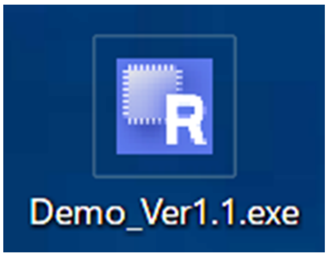


Figure 1-14 GUI Icon

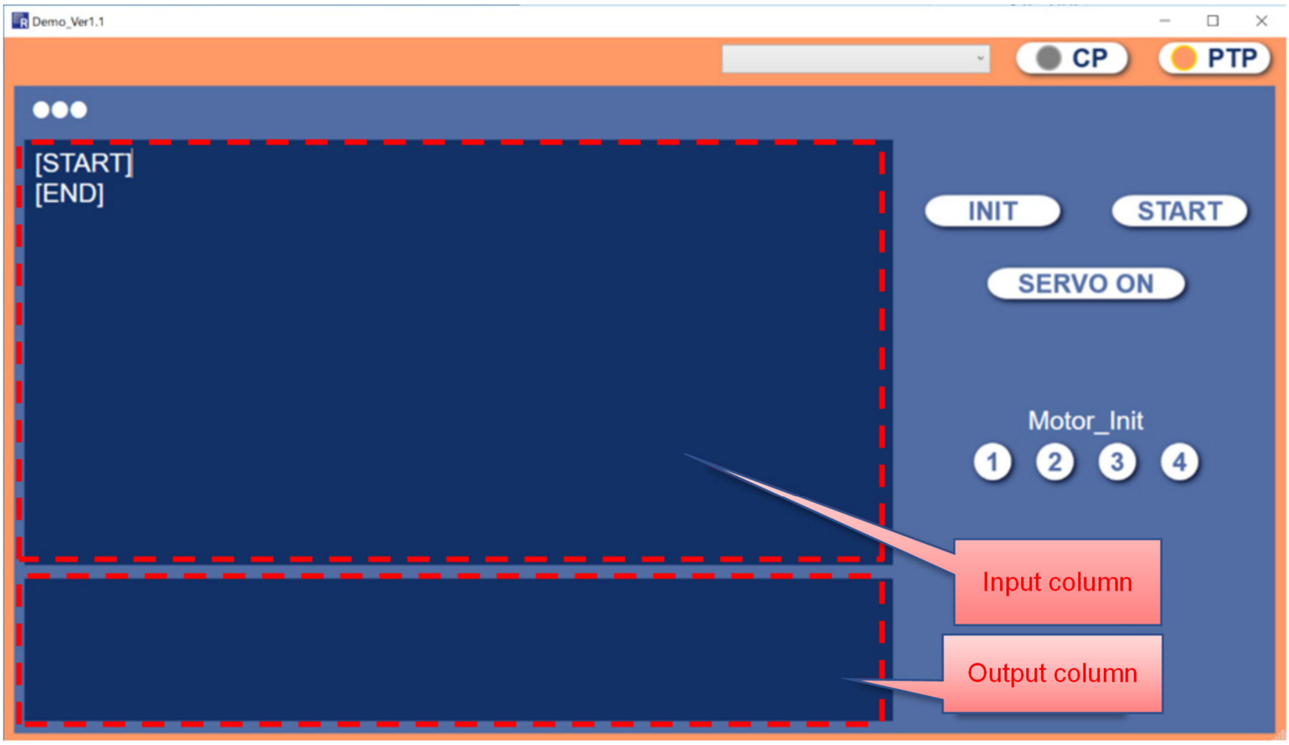


Figure 1-15 Screen after GUI Startup

1.7 Assembly and Wiring

Assemble the mechanical parts according to the assembly drawing in Figure No. RE00NR of *Structural drawings of robot arms (R12TU0118)*. The test operations in section 3 have to proceed before assembling the 42-mm and 85-mm square motors.

Figure 1-16 shows an overall view of the electrical wiring and Table 1-10 to Table 1-23 show the specifications for connecting the connectors. Wiring should be in accord with Table 1-10 to Table 1-23. Connect a debugger and the RMW if this is required. When connecting the RMW, a communications board such as the W2002 ICS++ (manufactured by Desk Top Laboratories Inc.) is convenient because it allows connection to a PC via a USB cable. For connecting a debugger and the power supply for the NC board, see *Renesas Starter Kit + for RX72M User's Manual (R20UT4391)*. Note that since some of the 42-mm square board's connection pins are used in common with the debugger and RMW, the two cannot be connected to this board at the same time.

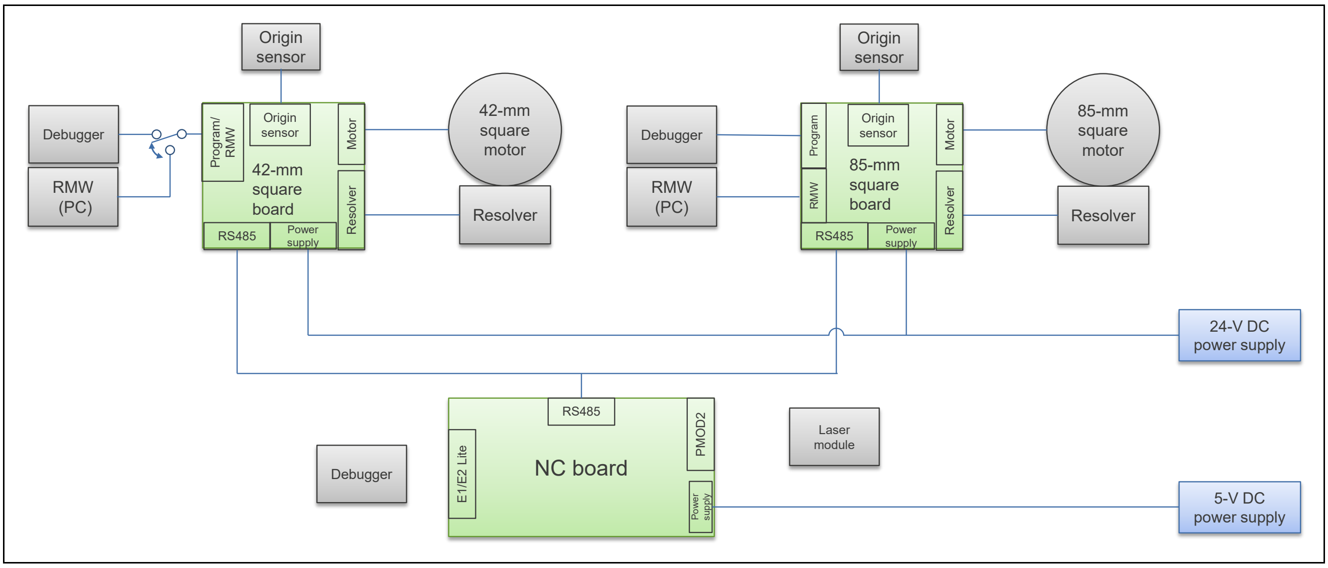


Figure 1-16 Overall View of Electrical Wiring

Table 1-10 Connection between the 42-mm Square Board and 42-mm Square Motor

42-mm Square Board Motor Output		Motor	
Pin No.	**Pin Name**	**Name**	**Meaning**
1	A–	A–	A phase –
2	A+	A+	A phase +
3	B+	B+	B phase +
4	B–	B–	B phase –

Table 1-11 Connection between the 42-mm Square Board and Resolver

42-mm Square Board Resolver		Resolver	
Pin No.	**Pin Name**	**Name**	**Meaning**
1	XBN	270° phase	Cos-
2	XBP	90° phase	Cos+
3	XAP	0° phase	Sin+
4	XAN	180° phase	Sin-
5	EXC	Excitation	Excitation

Table 1-12 Connection between the 42-mm Square Board, Emulator, and PC

42-mm Square Board Program/RMW		When Connected to Emulator		When Connected to PC (RMW)	
Pin No.	Pin Name	Name	Meaning	Name	Meaning
1	GND	GND	GND	GND	GND
2	RX	(Not used)		RX	RMW transmission
3	TX	(Not used)		TX	RMW reception
4	+5V	5V	Power supply from emulator	5V	5-V power supply
5	MD/FINED	FINE	FINE in emulator	(Not used)	
6	RES#	RESET	RES in emulator	(Not used)	

Table 1-13 Connection between the 42-mm Square Board and 24-V Power Supply

42-mm Square Board Power Supply		24-V Power Supply	
Pin No.	Pin Name	Name	Meaning
1	GND	GND	GND side
2	V+	Vout	+ side

Table 1-14 Connection between the 42-mm Square Board and NC Board

42-mm Square Board RS485		NC Board RS485 Header	
Pin No.	Pin Name	Name	Meaning
1	GND	GND	GND
2	B/Z	B	Differential communication line B
3	A/Y	A	Differential communication line A
4	NC	(Not used)	

Table 1-15 Connection between the 42-mm Square Board and Origin Sensor

42-mm Square Board Origin Sensor		Origin Sensor	
Pin No.	Pin Name	Name	Meaning
1	GND	GND	GND
2	+5V	Vcc	Power supply
3	RLS	(Not used)	
4	FLS	(Not used)	
5	DOG	OUT	Sensor output

Table 1-16 Connection between the 85-mm Square Board and 85-mm Square Motor

85-mm Square Board Motor Output		Motor	
Pin No.	**Pin Name**	**Name**	**Meaning**
1	A−	A−	A phase –
2	A+	A+	A phase +
3	B+	B+	B phase +
4	B−	B−	B phase –

Table 1-17 Connection between the 85-mm Square Board and Resolver

85-mm Square Board Resolver		Resolver	
Pin No.	**Pin Name**	**Name**	**Meaning**
1	XBN	270° phase	Cos-
2	XBP	90° phase	Cos+
3	XAP	0° phase	Sin+
4	XAN	180° phase	Sin-
5	EXC	Excitation	Excitation

Table 1-18 Connection between the 85-mm Square Board and Emulator

85-mm Square Board Program		Emulator	
Pin No.	**Pin Name**	**Name**	**Meaning**
1	GND	GND	GND side
2	RX	(Not used)	
3	TX	(Not used)	
4	+5V	5V	Power supply from emulator
5	MD/FINED	FINE	FINE in emulator
6	RES#	RESET	RES in emulator

Table 1-19 Connection between the 85-mm Square Board and PC

85-mm Square Board RMW		PC (RMW)	
Pin No.	**Pin Name**	**Name**	**Meaning**
1	GND	GND	GND
2	RX	RX	RMW transmission
3	TX	TX	RMW reception
4	+5V	5V	5-V power supply

Table 1-20 Connection between the 85-mm Square Board and 24-V Power Supply

85-mm Square Board Power Supply		24-V Power Supply	
Pin No.	**Pin Name**	**Name**	**Meaning**
1	GND	GND	GND side
2	V+	Vout	+ side

Table 1-21 Connection between the 85-mm Square Board and NC Board

85-mm Square Board RS485		NC Board RS485 Header	
Pin No.	**Pin Name**	**Name**	**Meaning**
1	GND	GND	GND
2	B/Z	B	Differential communication line B
3	A/Y	A	Differential communication line A
4	NC	(Not used)	

Table 1-22 Connection between the 85-mm Square Board and Origin Sensor

85-mm Square Board Origin Sensor		Origin Sensor	
Pin No.	**Pin Name**	**Name**	**Meaning**
1	GND	GND	GND
2	+5V	Vcc	Power supply
3	RLS	(Not used)	
4	FLS	(Not used)	
5	DOG	OUT	Sensor output

Table 1-23 Connection between the Laser Module and NC Board

Laser Module		NC Board PMOD2	
Name	**Meaning**	**Pin No.**	**Name**
Negative	–	5	GROUND
Positive	+	6	Board_3V3

2. Specifications of NC Software

2.1 Overview

This section gives a guide to use the RX72M-based robot arm trajectory control software (NC software) and explains its algorithms.

The NC software for the RTK5572MNDS10000BE board is only provided in the Motorola format (.mot).

2.1.1 Applicable Conditions and Functions

The applicable conditions for the NC software are as follows:

- Two degrees of freedom (two axes)
- The angle of the arm joints can be sensed by the sensors.
- The singularity of the arm (arm shape being a straight line) should not be passed.

The functions implemented by the NC software are as follows:

- Trajectory control
  - Interpolation calculation (linear or circular interpolation)
  - Acceleration or deceleration calculation (moving average filter)
  - Joint angle calculation (successive Jacobian calculations)
  - Monoaxial movement (no interpolation or angle specification)
- Consecutive operations (combinations of motion in straight lines and along arcs)

2.2 Definition of the Control Coordinate System

The following shows the terms used in this document and the definition of positive and negative of the rotation direction.

Table 2-1 Definition of the Control Coordinate System

Name	Description
Motor origin	The arm's sensor position corresponding to encoder angles of 0. The coordinates are to be calculated from the joint angle for the work origin.
Work origin	Origin of the coordinate system for use in calculating trajectories. (120, 120) in the development of this system.
Rotation direction of joint	Clockwise is considered the positive direction.

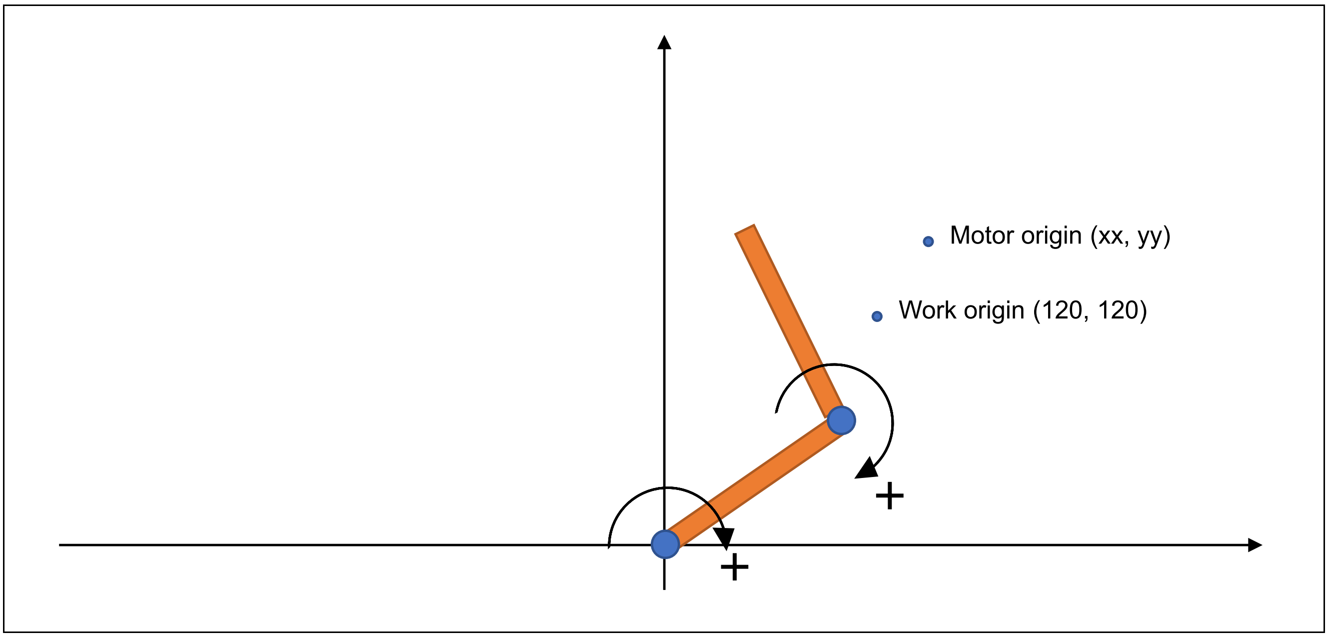


Figure 2-1 Definition of Control Coordinate System

2.3 Basic Manipulation

The angle of the API to be defined in this section is the angle from the Y axis in a clockwise direction, as shown in the figure in section 2.4.3. The arm lengths L1 and L2 are also those shown in the figure in section 2.4.3.

2.3.1 Procedure for Operations

The following table shows the sequence from turning on the power of the system, setting the offset, and applying CP control.

Table 2-2 Operation Procedure

Step	Description	Manipulation or Command	Enabling/Disabling of Coordinates and Offset
1	Turn on the power of the system.	—	Disabled
2	Turn on the servo.	GUI button	Disabled
3	Move the motor origin.	setup_motorzero	Disabled
4	Turn off the servo.	GUI button	Disabled
5	Move the arm to the work origin (120, 120) by hand.	—	Disabled
6	Read out the joint angle (encoder value).	output_state	Disabled
7	Set the offset (calibration). The RX72M calculates the coordinate system to be used in trajectory calculation from the offset that was set.	setup_workzeroangle	Enabled
8	Turn on the servo.	GUI button	Enabled
9	Set the CP mode.	GUI button	Enabled
10	Issue a CP control command.	setup_workzero, move_line, move_circle	Enabled
11	The arm is stopped because the entered operation has been completed or the stop command has been issued.	interrupt_stop	Enabled
12	Return to the motor origin. Be sure this is handled after the interrupt_stop command has been issued.	setup_motorzero	Enabled

2.3.2 List of Commands and APIs

The commands and APIs of this demo system are listed below.

Table 2-3 List of APIs (1)

Item	Command	Abbr.	Operation	Response
Setting (RX72M)	setup_motorspeed <tangential speed>	SMS	Sets the tangential speed [mm/s].	Normal: SMS OK Error: SMS NG
	setup_workzeroangle <joint angle 1> <joint angle 2>	SWA	Enters the joint angle [°, degrees)] at the work origin (coordinates are (120, 120)).	Normal: SWA OK Error: SWA NG
Setting (RX24T)	setup_cp	PCP	Sets the CP mode.	Normal: PCP OK Error: PCP NG
	setup_ptp	PTP	Sets the PTP mode.	Normal: PTP OK Error: PTP NG
	setup_on	SON	Turns on the power.	Normal: SON OK Error: SON NG
	setup_off	SOF	Turns off the power.	Normal: SOF OK Error: SOF NG
Operation instruction	setup_motorzero <joint 1> <joint 2>	SMZ	Returns to the motor origin. If the <joint 1> (0 or 1) or <joint 2> (0 or 1) argument is set to 1, return to the origin proceeds. <joint 1> and <joint 2> cannot be specified at the same time.	Normal: SMZ OK Error: SMZ NG
	setup_workzero	SWZ	Returns to the work origin.	Normal: SWZ OK Error: SWZ NG
	move_line <end flag> <end point x> <end point y>	MLI	Performs linear interpolation. If the end flag is a value other than 0, operation is slowed down and stopped at the end point.	Normal: MLI OK Error: MLI NG
	move_circle <end flag> <end point x> <end point y> <midpoint x> <midpoint y>	MCI	Performs circular interpolation. If the end flag is a value other than 0, operation is slowed down and stopped at the end point.	Normal: MCI OK Error: MCI NG
	move_angle <joint angle 1> <joint angle 2>	MAN	Moves the motor in the specified angle.	Normal: MAN OK Error: MAN NG
	move_wait <wait time>	MWA	Keeps the arm waiting for the specified wait time [ms].	Normal: MWA OK Error: MWA NG
State output	output_state	OST	Outputs the angle [° (degrees)] and tip coordinates [mm] of the current joint.	Normal: See section 2.3.3. Error: OST NG

Table 2-3 List of APIs (2)

Item	Command	Abbr.	Operation	Response
Loop operation	loop_start <loop count>	MST (LST)	Starts continuous operation. The <loop count> argument determines how many times the commands that were input in the range from loop_start to loop_end are to be executed.	Normal: MST OK (LST OK) Error: MST NG (LST NG)
	loop_end	MEN (LEN)	Finishes continuous operation.	Normal: MEN OK (LEN OK) Error: MEN NG (LEN OK)
Interrupt operation	interrupt_stop	IST	Stops operation of the arm. (the instruction that was input is discarded)	Normal: IST OK Error: IST NG

2.3.3 Output Format of output_state

The following figure shows the format of the parameters that are displayed in the output column of the GUI when the output_state command is executed.

Pm is the angle of the encoder in the motor and P is the angle in the coordinate system used in trajectory calculation.

```
Pm1 = xx.xx    Pm2 = xx.xx
P1 = xx.xx    P2 = xx.xx
(x y) =
xxx.xx xx.xx
```

Figure 2-2 Output Format of output_state (displayed in the output column of the GUI)

2.3.4 List of Parameters

Table 2-4 shows the parameters managed by the NC software.

Table 2-4 List of Managed Parameters

Medium item	Minor Item	Unit	Parameter Name	Range	Initial Value	R/W from GUI
CP mode in trajectory calculation	Tangential speed *1	mm/s	Trajectory_POINTSPEED	0 to 5,000	100	R/W
	Acceleration time *1	ms	Trajectory_ACCELTIME_ms	0 to 255	50	R/W
	Arm lengths (L1, L2) *1	mm	Trajectory_ARMLENGTH_L1 Trajectory_ARMLENGTH_L2	1 to 255	L1: 120 L2: 120	R/W
	Directions of motor rotation (θ1, θ2) *2	—	Trajectory_MOTORROLL_1 Trajectory_MOTORROLL_2	-1 or 1	θ1: 1 θ2: 1	R/W
	Step time *1	ms	Trajectory_STEPTIME	0.5 to 5 (multiple of 0.5)	1	R/W
	Permissible error *1	mm	Trajectory_ERRORRANGE	0.001 to 5	0.01	R/W
	Maximum error correction count *2	Count	Trajectory_MAX_ERROR_CORRECTION	0 to 255	2	R/W
	Offset (θ1, θ2) *1	° (degrees)	Trajectory_OFFSET_1 Trajectory_OFFSET_2	-180 to 180	θ1: 0 θ2: 0	Disabled
PTP mode *2	Maximum speed	RPM	Api_PTP_MAXSPEED	0 to 65,535	100	R/W
	Acceleration time	ms	Api_PTP_ACCERATIONTIME	0 to 65,535	50	R/W
Communication *2	Intervals of sync commands	μs	CtrlMotor_CP_SYNC_INTERVAL	500 to 5,000 (multiple of 500)	2,000	Disabled
	Timeout period in CP mode	μs	TIMEOUT_CP_us	0 to 1,000	100	Disabled
	Timeout period in modes other than CP mode	μs	TIMEOUT_OUT_us	0 to 5,000	1,000	Disabled
	Retry count	Count	NUM_RETRY	0 to 255	1	Disabled
	Size of buffer for data reception from GUI	Byte	CommPC_BUFSIZE_RCV	0 to 5,000	2,048	Disabled
	Size of buffer for commands from GUI	Number of commands	COMMAND_SIZE	0 to 1,000	100	Disabled
	Size of buffer for data transmission to GUI	Byte	CommPC_BUFSIZE_SEND	0 to 1,000	4,096	Disabled
	Baud rate for communication with RX24T	bps	RX24T_BAUDRATE	10M, 5M, 4M, 2M, or 1M bps is assumed	2,000,000	Disabled
	Baud rate for communication with PC	bps	—	115.2 kbps only	115,200	Disabled

Notes: 1. A decimal number can be entered.
2. Only integers can be entered.

2.3.5 Error Processing

The NC software determines whether a response from the RX24T is an error and handles error processing if an error has occurred. The following shows the error determination flow and its details and processing.

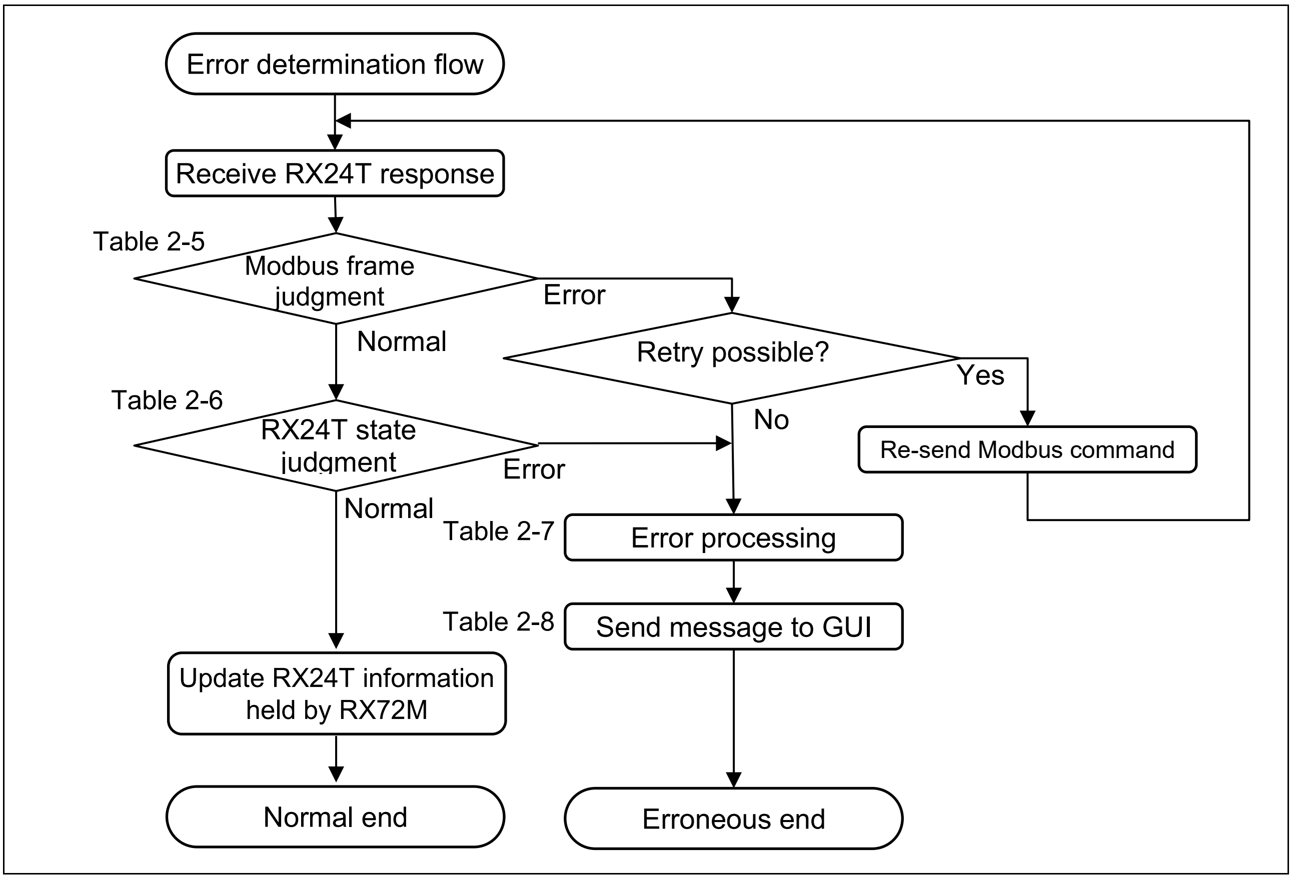


Figure 2-3 Error Determination Flow

Table 2-5 Modbus Frame Judgment

No.	Error Condition
A-1	A response was received during broadcasting.
A-2	A timeout has occurred because a response could not be received.
A-3	The CRC in the received response does not match.
A-4	The function code in the received response is an exception code.
A-5	The function code in the received response does not match.
A-6	The slave address in the received response does not match.

Table 2-6 RX24T State Judgment

No.	Error Condition
B-1	The RDY signal is 0.
B-2	The ERR0 to ERR3 bits of the 1-bit tangent-point data are non-0 in CP control mode.
B-3	The ERR0 to ERR3 bits of the 1-bit tangent-point data are non-0 during return to the origin.
B-4	A sync command receive error was received N times in a row from the same slave in CP control mode. (N: Retry count + 1)
B-5	When confirming the state of the RX24T before applying CP control, the position determination end bit of the 1-bit tangent-point data is 0.
B-6	When confirming the state of the RX24T before applying CP control, the during return to origin bit of the 1-bit tangent-point data is 1.
B-7	During return to the motor origin, the position determination end bit of the 1-bit tangent-point data is 0.
B-8	In PTP control mode, the during return to origin bit of the 1-bit tangent-point data is 1.
B-9	When the state of the arm is output, the start of return to origin bit of the 1-bit tangent-point data is 0.
B-10	When the state of the arm is output, the during return to origin bit of the 1-bit tangent-point data is 1.
B-11	The cycle of a sync command is delayed in CP control mode.

Table 2-7 Error Processing

No.	Error Processing
C-1	After shifting the slave to PTP control mode by broadcasting, direct the servo to be turned off.

Table 2-8 Messages Sent to the GUI

Corresponding No.	Message
A-1	[Error] Received response in Broadcast command
A-2	[Error] Time out
A-3	[Error] CRC error
A-4, B-4	[Error] Exception response: FNC = 0x (n1), CODE = (n2) n1: Function code (8-bit value with MSB = 1) n2: Exception code <Examples of exception codes> • A CP control position reference value was sent in a mode other than CP control mode. (Exception code = 1) • A PTP control position reference value was sent in a mode other than PTP control mode. (Exception code = 1) • A non-existent address was specified. (Exception code = 2) • An invalid data range was set. (Exception code = 3) • The sync signal query immediately after a CP position reference has not been received by the RX24T. (Exception code = 4)
A-5	[Error] Mismatch FNC-No
A-6	[Error] Mismatch Slave-address
B-1	[Error] RDY = 0
B-2, B-3	[Error] ERR0–ERR3: 0x (n) n: Four bits [15:12] of a 1-bit tangent-point data address (error information)
B-5 B-6 B-7 B-8 B-9 B-10	[Error] Arm moving
B-11	[Error] Frequency of CP

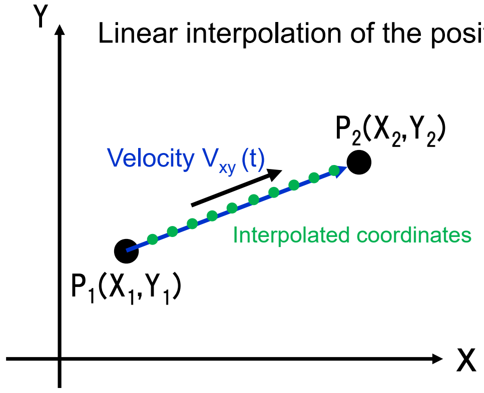
2.4 Implementation Method

Sections 2.4.1 to 2.4.3 show calculations used in the implemented functions.

2.4.1 Calculations for Interpolation

Calculate coordinates for interpolating the coordinates in motion between two points.

- Linear interpolation



Assuming the velocity is V_X or V_Y and the trajectory velocity is V_xy (t), the velocity is divided by the amounts of X-axis and Y-axis motion.

$$V_X = V_{xy}(t) \times \frac{X_2 - X_1}{\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}}$$

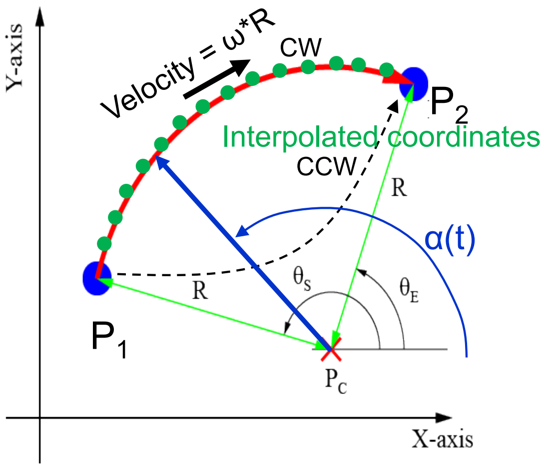
$$V_Y = V_{xy}(t) \times \frac{Y_2 - Y_1}{\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}}$$

Calculate the interpolated coordinates from V_X, V_Y.

$$\mathrm{X(t)} = X_1 + V_X \times t$$

$$\mathrm{Y(t)} = Y_1 + V_Y \times t$$

- Circular interpolation



Assuming the coordinates of the center of the circle containing the arc are Pc = (xc, yc), the equation for a circle can be used for calculation as follows:

$$(x_1 - \mathrm{xc})^2 + (y_1 - yc)^2 = R^2$$

$$(x_2 - \mathrm{xc})^2 + (y_2 - yc)^2 = R^2$$

Since they are a pair of simultaneous quadratic equations, there are two solutions (clockwise (CW) trajectory and counterclockwise (CCW) trajectory).

For a CW trajectory, assuming that the angle through which the circular trajectory passes is α (t), the position and velocity can be obtained as follows.

CW: Clockwise, CCW: Counterclockwise

$$\mathrm{\alpha(t)} = \alpha_s + \omega \times t$$

$$\mathrm{X(t)} = \mathrm{R} \times \cos\alpha(t) + X_C$$

$$\mathrm{Y(t)} = \mathrm{R} \times \sin\alpha\,(t) + Y_C$$

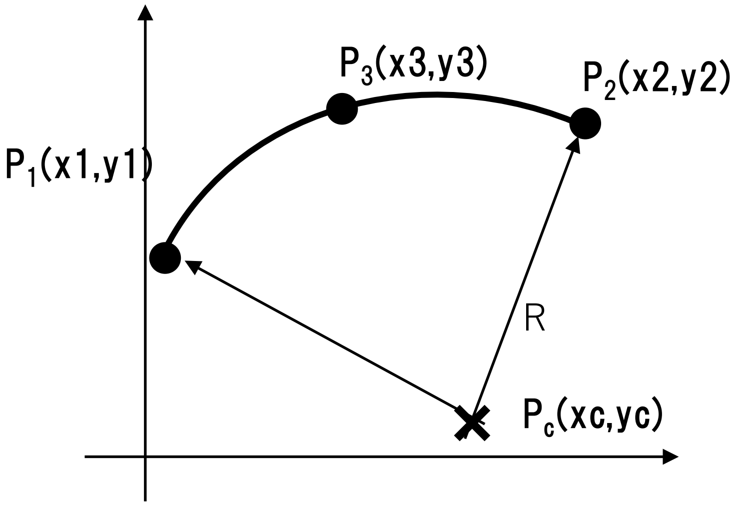
Differentiate the position and velocity by time, and calculate X and Y per unit time.

$$\frac{dX}{dt} = -R \times \frac{d\alpha}{dt} \times \sin\alpha\,(t)$$

$$\frac{dY}{dt} = R \times \frac{d\alpha}{dt} \times \cos\alpha\,(t)$$

- Central coordinates of an arc

Calculate the central coordinates of a circle passing through three points and then calculate the radius from the obtained central coordinates.



$$\begin{cases} (x_1 - xc)^2 + (y_1 - yc)^2 = r^2 & Equation\ 1 \\ (x_2 - xc)^2 + (y_2 - yc)^2 = r^2 & Equation\ 2 \\ (x_3 - xc)^2 + (y_3 - yc)^2 = r^2 & Equation\ 3 \end{cases}$$

Calculate under the condition that equation 1 is equal to equation 2.

$$(x_1 - xc)^2 + (y_1 - yc)^2 = (x_2 - xc)^2 + (y_2 - yc)^2$$

$$(x_1 + y_1 - 2xc)(x_1 - x_2) + (y_1 + y_2 - 2xy)(y_1 - y_2) = 0$$

Similarly, calculate under the condition that equation 2 is equal to equation 3.

$$\begin{cases} (x_1 - x_2)xc + (y_1 - y_2)yc = \frac{1}{2}\{(x_1^2 - x_2^2) + (y_1^2 - y_2^2)\} \\ (x_2 - x_3)xc + (y_2 - y_3)yc = \frac{1}{2}\{(x_2^2 - x_3^2) + (y_2^2 - y_3^2)\} \end{cases}$$

On the assumption of $X_i = x_i^2 + y_i^2$, perform substitution to form a determinant.

$$\begin{pmatrix} x_1 - x_2 & y_1 - y_2 \\ x_2 - x_3 & y_2 - y_3 \end{pmatrix} \begin{pmatrix} xc \\ yc \end{pmatrix} = \frac{1}{2} \begin{pmatrix} X_1 - X_2 \\ X_2 - X_3 \end{pmatrix}$$

On the assumption of $\begin{pmatrix} a & b \\ c & d \end{pmatrix} = \begin{pmatrix} x_1 - x_2 & y_1 - y_2 \\ x_2 - x_3 & y_2 - y_3 \end{pmatrix}$, calculate the inverse matrix.

$$\begin{pmatrix} xc \\ yc \end{pmatrix} = \frac{1}{2} \times \frac{1}{ad - bc} \times \begin{pmatrix} d & -b \\ -c & a \end{pmatrix} \times \begin{pmatrix} X_1 - X_2 \\ X_2 - X_3 \end{pmatrix}$$

2.4.2 Acceleration or Deceleration Calculation

Calculate the speed of an arm using a moving average filter.

- Calculation with moving average filter

When converting to a discrete value system, the following equation is obtained due to integral characteristic $= \mathrm{dT} \div (1 - Z^{-1})$.

$$G_f(z) = \{(1 - Z^{-M}) \times (dT \div \tau)\} \div (1 - Z^{-1})$$

$\tau = \mathrm{M} \times \mathrm{dT}$ dT = Sampling time, M = Sampling count

$$G_f(z) = \{(1 - Z^{-M}) \div M\} \div (1 - Z^{-1})$$

On the assumption of the input is X and the output is Y, the following is obtained.

$$\mathrm{Y} = G_f(z) \times X$$

$$(1 - Z^{-1})Y = (1 - Z^{-M}) \div M \times X$$

$$\mathrm{Y}(n) = Y(n-1) + \frac{1}{M} \times \{X(n) - X(n-M)\}$$

Initial value

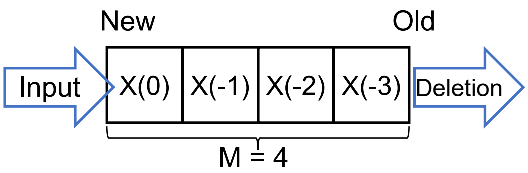
$$\mathrm{Y}(0) = \frac{1}{M} \times \{X(0) + X(-1) + X(-2) \cdots X(-M+1)\}$$

The initial values are the XY coordinate values of the position for returning to the motor origin or the position after PTP control.

General examples of the operation of the moving average filter are shown below and on the next page.

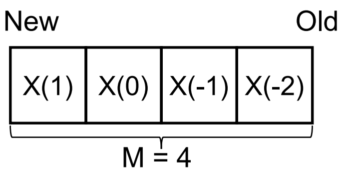
Note that the moving average is assumed to be taken from the most recent four values in the filter in the examples of operation.

t = 0: Initial value



t = 1: Sampling has been handled once

Newly acquire X (1) data and shift the data in the filter.



- Examples: When expanding to a differential equation on the assumption of M = 4
  - t = 0: Initial value

$$Y(0) = \frac{1}{4} \times \{X(0) + X(-1) + X(-2) + X(-3)\}$$

New			Old
X(0)	X(-1)	X(-2)	X(-3)

M = 4

  - t = 1

$$Y(1) = Y(0) + \frac{1}{4} \times \{X(1) - X(-3)\} = \frac{1}{4} \times \{X(1) + X(0) + X(-1) + X(-2)\}$$

New			Old
X(1)	X(0)	X(-1)	X(-2)

M = 4

  - t = 2

$$Y(2) = Y(1) + \frac{1}{4} \times \{X(2) - X(-2)\} = \frac{1}{4} \times \{X(2) + X(1) + X(0) + X(-1)\}$$

New			Old
X(2)	X(1)	X(0)	X(-1)

M = 4

  - t = 3

$$Y(3) = Y(2) + \frac{1}{4} \times \{X(3) - X(-1)\} = \frac{1}{4} \times \{X(3) + X(2) + X(1) + X(0)\}$$

New			Old
X(3)	X(2)	X(1)	X(0)

M = 4

  - t = 4

$$Y(4) = Y(3) + \frac{1}{4} \times \{X(4) - X(0)\} = \frac{1}{4} \times \{X(4) + \underbrace{X(3)} + X(2) + X(1)\}$$

n-M = Data of the operation four times before (past) is used (oldest data in buffer)

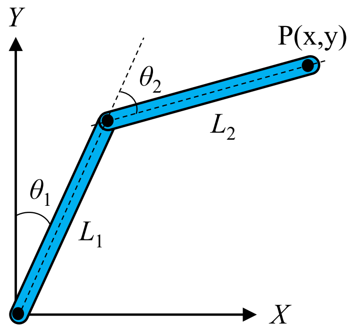
New			Old
X(4)	X(3)	X(2)	X(1)

M = 4

2.4.3 Joint Angle Calculation

Calculate the angle of each joint from the tip coordinates of the arm by using successive Jacobian calculations.

- Successive Jacobian calculations



Calculate the tip coordinates (x, y) from θ_1 and θ_2.

$$x = L_1 \sin\theta_1 + L_2 \sin\ (\theta_1 + \theta_2)$$

$$y = L_1 \cos\theta_1 + L_2 \cos\ (\theta_1 + \theta_2)$$

Differentiate them by time.

$$\dot{x} = \{L_1 \cos\theta_1 + L_2 \cos\ (\theta_1 + \theta_2)\}\dot{\theta_1} + L_2 \cos\ (\theta_1 + \theta_2)\,\dot{\theta_2}$$

$$\dot{y} = \{L_1 \sin\theta_1 + L_2 \sin\ (\theta_1 + \theta_2)\}\dot{\theta_1} + L_2 \sin\ (\theta_1 + \theta_2)\,\dot{\theta_2}$$

Change them into a matrix.

$$\begin{bmatrix}\dot{x}\\ \dot{y}\end{bmatrix} = \begin{bmatrix} L_1 \cos\theta_1 + L_2 \cos(\theta_1 + \theta_2) & L_2 \cos(\theta_1 + \theta_2) \\ -L_1 \sin\theta_1 - L_2 \sin(\theta_1 + \theta_2) & -L_2 \sin(\theta_1 + \theta_2)\end{bmatrix}\begin{bmatrix}\dot{\theta_1}\\ \dot{\theta_2}\end{bmatrix}$$

Change the matrix into a form to obtain θ_1 and θ_2, and differentiate both sides by time.

$$\begin{bmatrix}\frac{d\theta_1}{dt}\\ \frac{d\theta_2}{dt}\end{bmatrix} = \begin{bmatrix} L_1 \cos\theta_{1i} + L_2 \cos(\theta_{1i} + \theta_{2i}) & L_2 \cos(\theta_{1i} + \theta_{2i}) \\ -L_1 \sin\theta_{1i} - L_2 \sin(\theta_{1i} + \theta_{2i}) & -L_2 \sin(\theta_{1i} + \theta_{2i})\end{bmatrix}^{-1}\begin{bmatrix}\frac{dX_i}{dt}\\ \frac{dY_i}{dt}\end{bmatrix}$$

$dX_i = X_i - X_{i-1}$ and $dY_i = Y_i - Y_{i-1}$ are assumed.

Add the difference of the angle to the joint angle in the previous cycle and assume the result as the current joint angle.

$$\begin{bmatrix}\theta_{1i}\\ \theta_{2i}\end{bmatrix} = \begin{bmatrix}\theta_{1i-1}\\ \theta_{2i-1}\end{bmatrix} + \begin{bmatrix} L_1 \cos\theta_{1i-1} + L_2 \cos(\theta_{1i-1} + \theta_{2i-1}) & L_2 \cos(\theta_{1i-1} + \theta_{2i-1}) \\ -L_1 \sin\theta_{1i-1} - L_2 \sin(\theta_{1i-1} + \theta_{2i-1}) & -L_2 \sin(\theta_{1i-1} + \theta_{2i-1})\end{bmatrix}^{-1}\begin{bmatrix}\frac{dX_i}{dt}\\ \frac{dY_i}{dt}\end{bmatrix}$$

Obtain the inverse-Jacobian matrix.

$$\begin{bmatrix} L_1\cos\theta_{1i-1} + L_2\cos(\theta_{1i-1}+\theta_{2i-1}) & L_2\cos(\theta_{1i-1}+\theta_{2i-1}) \\ -L_1\sin\theta_{1i-1} - L_2\sin(\theta_{1i-1}+\theta_{2i-1}) & -L_2\sin(\theta_{1i-1}+\theta_{2i-1}) \end{bmatrix}^{-1}$$

In the inverse-Jacobian matrix, replace the equations with the following contents.

$\cos\theta_{1i-1} = \cos 1$,

$\cos(\theta_{1i-1}+\theta_{2i-1}) = \cos 1p2$,

$\sin\theta_{1i-1} = \sin 1$,

$\sin\theta_{2i-1} = \sin 2$,

$\sin(\theta_{1i-1}+\theta_{2i-1}) = \sin 1p2$

$$\begin{bmatrix} L_1\cos 1 + L_2\cos 1p2 & L_2\cos 1p2 \\ -L_1\sin 1 - L_2\sin 1p2 & -L_2\sin 1p2 \end{bmatrix}^{-1}$$

$$= \frac{1}{(L_1\cos 1 + L_2\cos 1p2)\times(-L_2\sin 1p2) - (L_2\cos 1p2)\times(-L_1\sin 1 - L_2\sin 1p2)} \begin{bmatrix} -L_2\sin 1p2 & -L_2\cos 1p2 \\ -(-L_1\sin 1 - L_2\sin 1p2) & L_1\cos 1 + L_2\cos 1p2 \end{bmatrix}$$

$$= \frac{1}{(-L_1L_2\cos 1\sin 1p2) + (-{L_2}^2\cos 1p2\sin 1p2) + (L_2L_1\sin 1\cos 1p2) + ({L_2}^2\cos 1p2\sin 1p2)} \begin{bmatrix} -L_2\sin 1p2 & -L_2\cos 1p2 \\ L_1\sin 1 + L_2\sin 1p2 & L_1\cos 1 + L_2\cos 1p2 \end{bmatrix}$$

$$= \frac{1}{(-L_1L_2\cos 1\sin 1p2) + (L_2L_1\sin 1\cos 1p2)} \begin{bmatrix} -L_2\sin 1p2 & -L_2\cos 1p2 \\ L_1\sin 1 + L_2\sin 1p2 & L_1\cos 1 + L_2\cos 1p2 \end{bmatrix}$$

$$= \frac{1}{L_1L_2(\sin 1\cos 1p2 - \cos 1\sin 1p2)} \begin{bmatrix} -L_2\sin 1p2 & -L_2\cos 1p2 \\ L_1\sin 1 + L_2\sin 1p2 & L_1\cos 1 + L_2\cos 1p2 \end{bmatrix}$$

From the additive theorem of trigonometric functions:

$$= \frac{1}{-L_1L_2 sin\ 2} \begin{bmatrix} -L_2\sin 1p2 & -L_2\cos 1p2 \\ L_1\sin 1 + L_2\sin 1p2 & L_1\cos 1 + L_2\cos 1p2 \end{bmatrix}$$

Replace part of the equation for obtaining the current joint angle with the above.

$$\begin{bmatrix} \theta_{1i} \\ \theta_{2i} \end{bmatrix} = \begin{bmatrix} \theta_{1i-1} \\ \theta_{2i-1} \end{bmatrix} + \frac{1}{-L_1L_2\sin\theta_{2i-1}} \begin{bmatrix} -L_2\,sin(\theta_{1i-1}+\theta_{2i-1}) & -L_2\,cos(\theta_{1i-1}+\theta_{2i-1}) \\ L_1\,sin\,\theta_{1i-1} + L_2\,sin(\theta_{1i-1}+\theta_{2i-1}) & L_1\,cos\,\theta_{1i-1} + L_2\,cos(\theta_{1i-1}+\theta_{2i-1}) \end{bmatrix} \begin{bmatrix} \frac{dX_i}{dt} \\ \frac{dY_i}{dt} \end{bmatrix}$$

Solve the determinant. The following equations are actually included in the program.

$$\theta_{1i} = \theta_{1i-1} + \frac{1}{-L_1L_2\sin\theta_{2i-1}}\left\{-L_2\,sin(\theta_{1i}+\theta_{2i})\times\frac{dX_i}{dt} - L_2\,cos(\theta_{1i}+\theta_{2i})\times\frac{dY_i}{dt}\right\}$$

$$\theta_{2i} = \theta_{2i-1} + \frac{1}{-L_1L_2\sin\theta_{2i-1}}\left[\{L_1\,sin\,\theta_{1i-1} + L_2\,sin(\theta_{1i-1}+\theta_{2i-1})\}\times\frac{dX_i}{dt} + \{L_1\,cos\,\theta_{1i-1} + L_2\,cos(\theta_{1i-1}+\theta_{2i-1})\}\times\frac{dY_i}{dt}\right]$$

2.4.4 Error Correction

The following shows calculations used in error correction for successive Jacobian calculations.

Calculate the coordinates (X, Y) from the joint angle of successive Jacobian calculation results.

$$\mathrm{X} = \mathrm{L}_1 \sin\theta_1 + L_2 \sin(\theta_1 + \theta_2)$$

$$\mathrm{Y} = \mathrm{L}_1 \cos\theta_1 + L_2 \cos(\theta_1 + \theta_2)$$

Calculate the error between the obtained coordinates and interpolated coordinates (expectations).

$$\Delta\mathrm{X} = X_{hokan} - X$$

$$\Delta\mathrm{Y} = Y_{hokan} - Y$$

Calculate the error of the angle from the error of the coordinates using Jacobian matrix J.

$$\begin{bmatrix}\Delta\theta_1 \\ \Delta\theta_2\end{bmatrix} = J^{-1}\begin{bmatrix}\Delta X \\ \Delta Y\end{bmatrix}$$

Treat the result of $\theta_{1,2} + \Delta\theta_{1,2}$ as $\theta_{1,2}$.

Error correction should be handled until $\Delta\mathrm{X}$ and $\Delta\mathrm{Y}$ become smaller than permissible error ϵ.

2.5 Time Charts

The figures below show the typical and maximum time charts in CP control mode.

The processing times in trajectory calculation were measured from a simulator, but the times for command analysis and communications are those which are theoretically expected.

The timeout for waiting for a response in transfer is 100 μs. If there was no response during the response waiting time, only a single retry is allowed. If timeouts occur twice in a row, a communications error is judged to have occurred; communications operations are stopped and the servo is turned off. Accordingly, as shown in Figure 2-5, the state that requires the maximum time is when a retry proceeds because a timeout had occurred due to no response within 100 μs in the first attempt at transfer (78 commands) for both slave 1 and slave 2, and the response to the second transfer occurred just before a timeout (99 μs).

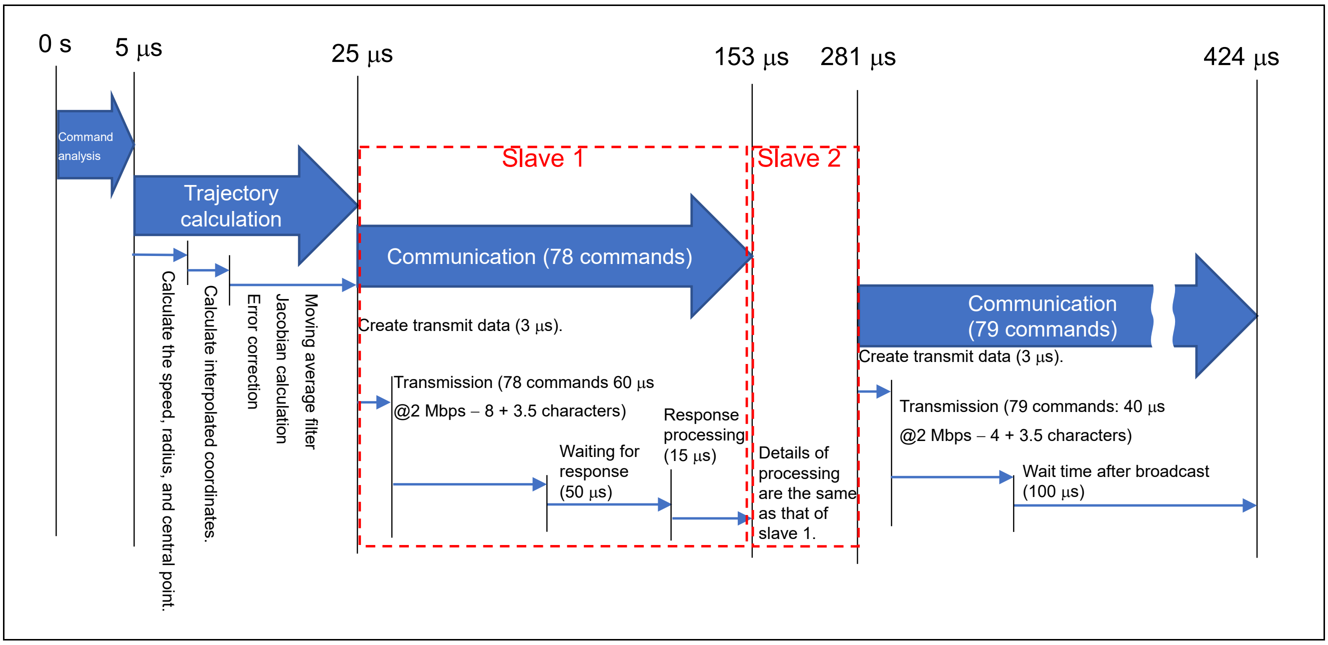


Figure 2-4 Time Chart (Typ.)

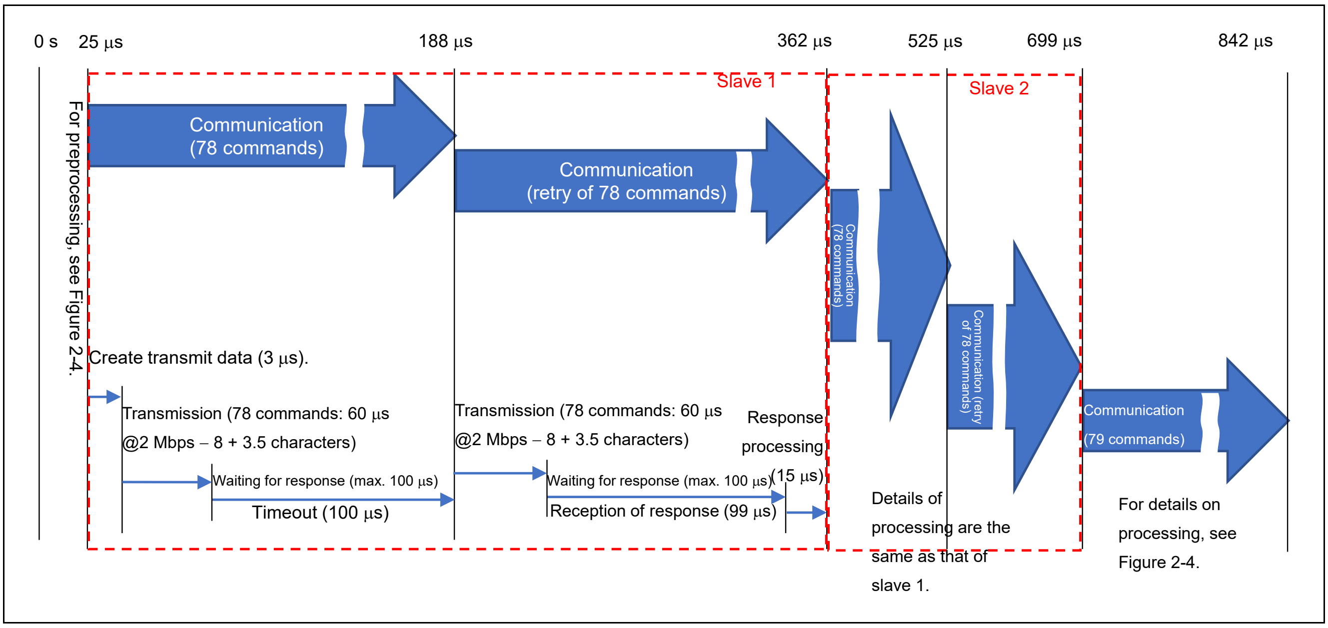


Figure 2-5 Time Chart (Max.)

2.6 List of Used Peripheral Functions and Pins

Table 2-9 and Table 2-10 respectively list the peripheral functions and pins used by the NC software.

Table 2-9 List of Used Peripheral Functions

Peripheral Function	Purpose
SCI6	Communication between PC and RX72M
SCI10	Communication between RX72M and RX24T
CRC	CRC calculation
CMT0	Cycle of sync command in CP control mode
CMT1	Intervals of 2 characters of Modbus communication
CMT2	Intervals of 1.5 characters of Modbus communication
CMT3	General timeout 1. CP control: 100 us 2. Other than CP control: 1000 us
TMR0_TMR1 (16 bits)	General-purpose wait
Port PL0	RS-485 transmission enable pin

Table 2-10 List of Used Pins

Pin No.	Pin Name	I/O	Purpose
E3	P00	Output	TX pin for PC connection (SCI6)
D5	P01	Input	RX pin for PC connection (SCI6)
N9	PC7	Output	TX pin for RS-485 (SCI10)
N3	P86	Input	RX pin for RS-485 (SCI10)
H11	PL0	Output	RS-485 transmission enable pin
J1	XTAL	Input	24-MHz crystal resonator
H1	EXTAL	Input	24-MHz crystal resonator
K1	PH7	Output	ET-XICLK (25-MHz output)

2.6.1 SCI6 and SCI10

In asynchronous mode, SCI6 is used for communication between PC-GUI and RX72M and SCI10 is used for communication between RX72M and RX24T. Table 2-11 shows the settings of SCI6 and Table 2-12 shows the settings of SCI10.

Table 2-11 SCI6 Setting

Item	Setting
Serial communication mode	Asynchronous mode
Start-bit detection	Low level of RXD6 pin
Data length	8 bits
Parity	Disabled
Stop bit	1 bit
Data transfer direction	LSB first
Transfer speed	• Transfer clock: Internal clock • Bit rate: 115200 bps • Bit rate modulation: Disabled • SCK6 pin function: SCK6 is not used
Noise filter	Used
Hardware flow control	Disabled
Data match detection	Disabled
Data processing	Processing of transmit data: Processed in interrupt service routine Processing of receive data: Processed in interrupt service routine
Interrupts	Priority of TXI6: 6 Priority of RXI6: 6 Receive error interrupt: Enabled Priority of TEI6 or ERI6 (group BL0): 6
Callback functions	Transmission complete Reception complete Receive error
Input/output pins	• Output: TXD6 (P00) • Input: RXD6 (P01)

Table 2-12 SCI10 Setting

Item	Setting
Serial communication mode	Asynchronous mode
FIFO mode	Non-FIFO mode
Start-bit detection	Low level of RXD10 pin
Data length	8 bits
Parity	Disabled
Stop bit	1 bit
Data transfer direction	LSB first
Transfer speed	• Transfer clock: Internal clock • Bit rate: 2 Mbps • Bit rate modulation: Enabled • SCK10 pin function: Not in use
Noise filter	Used
Hardware flow control	Disabled
Data match detection	Disabled
Data processing	Processing of transmit data: Processed in interrupt service routine Processing of receive data: Processed in interrupt service routine
Interrupts	Priority of TXI10: 10 Priority of RXI10: 10 Receive error interrupt: Enabled Priority of TEI10 or ERI10 (group AL0): 10
Callback functions	Transmission complete Reception complete Receive error
Input/output pins	• Output: TXD10 (PC7) • Input: RXD10 (P86)

2.6.2 CRC

A CRC calculator is used for confirming the communication contents. Table 2-13 shows the CRC settings.

Table 2-13 CRC Setting

Item	Setting
Generating polynomial	CRC_16
Bit order	LSB
Initial value	0xFFFF
Inversion of calculation result	No

2.7 Project Configuration

2.7.1 Operating Conditions

The following shows the operating conditions for a project.

Table 2-14 Operating Conditions

Item	Description
Microcontroller	RX72M R5F572MNDDBD Power supply voltage (VCC): 3.3 V Operating frequency ICLK: 240 MHz PCLKA: 120 MHz (SCI10) PCLKB: 60 MHz (SCI6, CMT0 to CMT3, TMR0_TMR1)
Board	RTK5572MNDC00000BJ
IDE	e^2 studio V7.7.0
Compiler	CC-RX V3.02.00
Emulator	E1 emulator

2.7.2 Configuration Image

The figure below shows a configuration image classified by the function of a project.

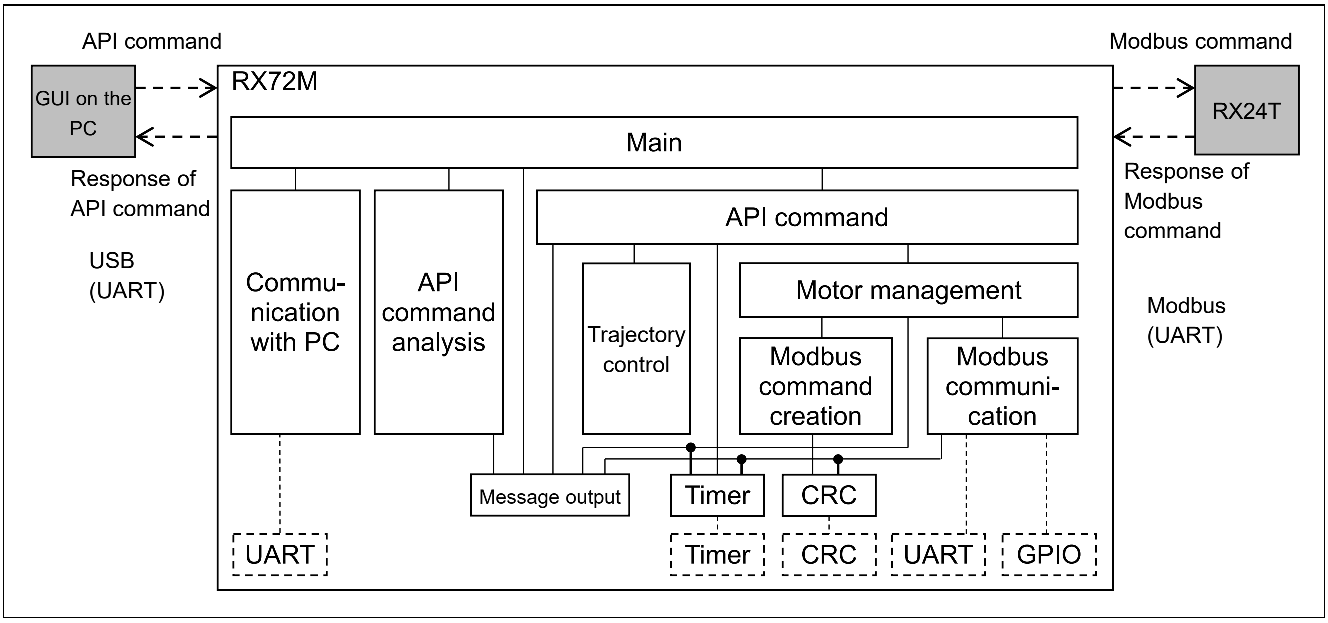


Figure 2-6 Configuration Image

3. Operating the Demo System

This section explains the method of operating the demo system. Start by tuning the motors and demo system and training in the demonstration operations through the GUI, and then operate the arm of the demo system as desired.

3.1 Tuning

3.1.1 Adjusting the Offset

The position of a magnetic pole of a motor needs to be set correctly by software when a resolver is to be used in driving a motor. Also, the offset of the current sensing value needs to be adjusted so that the current can be adjusted to zero. This manipulation is called offset adjustment, and it should be according to the following procedure. Since some of the adjustment cannot be handled normally if a load is attached to a motor, each motor must have no load during the adjustment. Note that this manipulation only has to proceed once because the result of offset adjustment is written to flash memory in the microcontroller. The offset will not require re-adjustment even after the power has been turned off. However, the offset must definitely be adjusted following a change to a motor or control board.

1. Connect an emulator (E1 or E2 Lite) to the 42-mm square board or 85-mm square board and write the sample software for driving each of the motors (RX24T_ROBOT42_STM_RSLV_FOC for the 42-mm square board and RX24T_ROBOT42_STM_RSLV_FOC for the 85-mm square board).
2. After disconnecting the emulator, connect a PC in which the RMW has been installed via the RMW communication board.
3. Start the RMW and write 0 to com_u1_sw_userif in the control window to switch to the RMW operating mode.
4. Write 7 to com_u1_system_mode to perform offset adjustment.
5. After reading the value in com_u1_system_mode and confirming that the value has become 0, write 8 to com_u1_system_mode to perform flash programming.
6. Read the value in com_u1_system_mode. If the value has become 0, flash programming has been completed and offset adjustment has finished.

The above manipulation has to be handled for both the 42-mm square motor and 85-mm square motor.

Upon completing the above procedure, follow the procedure below as a test operation to issue instructions for the 90° and –90° positions to confirm whether movement to the desired positions is achieved. If the operation does not proceed correctly, try adjusting the offset again.

1. Write 1 to com_u1_system_mode to start controlling the position.
2. Write 90 to com_f4_pos_ref_deg.
3. Write 1 to com_u1_enable_write and confirm that the motor is rotated clockwise by 90 degrees.
4. Write -90 to com_f4_pos_ref_deg.
5. Write 0 to com_u1_enable_write and confirm that the motor is rotated counterclockwise by 90 degrees.
6. Write 0 to com_u1_system_mode to stop controlling the position.

3.1.2 Adjusting the Resonance Suppressing Filters

Since this demo system has a gearless structure in which the arms and motors are directly connected to each other, mechanical resonance will tend to occur, so tuning of the resonance suppressing filters will be necessary. The resonance suppressing filters for both the 42-mm square board and 85-mm square board are adjusted by the following procedure with the 42-mm square motor and 85-mm square motor connected to the respective arms.

1. Drive the motor by sending a desired position reference from the RMW, measure the frequency characteristics between the speed instruction at that time and the actual speed by using an FFT analyzer, and identify the resonance frequency (see Figure 3-1). If a resonance peak and an antiresonance peak are present, record the frequency of each peak. If multiple resonance points are visible, record the resonance frequencies in the same manner. Note that if you do not have an FFT analyzer when an appropriate position reference value is given, monitor the feedback value of the position signal in the microcontroller by using a D/A converter or an optional external sensor (e.g., vibration sensor) and estimate the resonance frequency from the resonance waveform (see Figure 3-2).
2. Use software to change the arguments of R_MTR_SRFOC_SetTorqFilterParam, which is called from the init_torq_filter function in r_app_main.c within the project of the sample software for motor driving, to suit the resonance frequency and execute rebuilding.
3. Connect the emulator to each board and write the rebuilt software.
4. Connect the RMW and give a desired position reference again to confirm that the resonance characteristics have been improved. If not, return to step 1 and revise the filter.

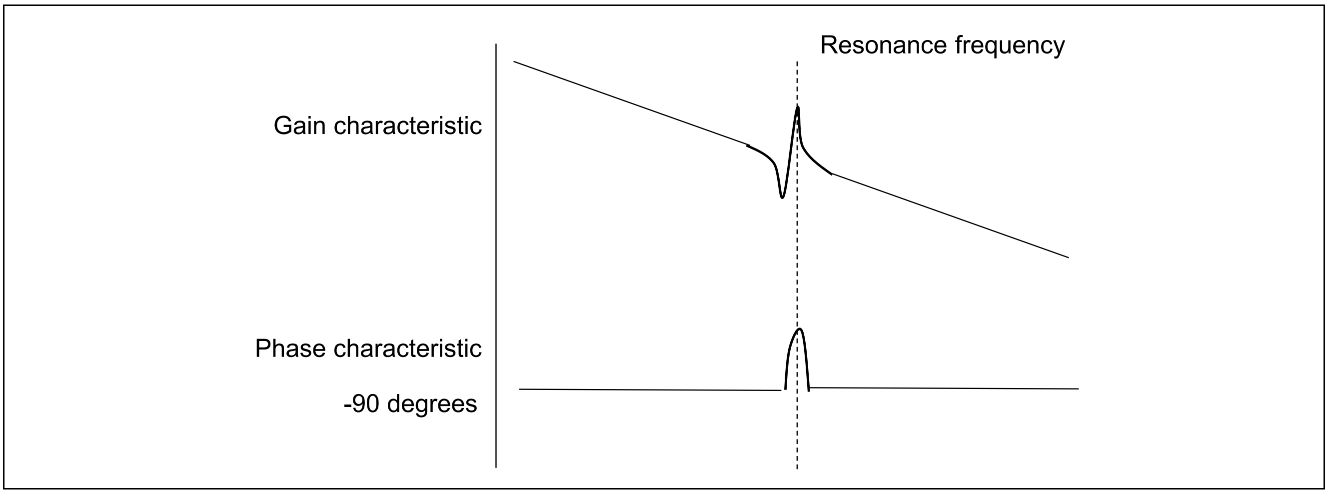


Figure 3-1 Confirmation of Resonance Frequency by FFT Analyzer

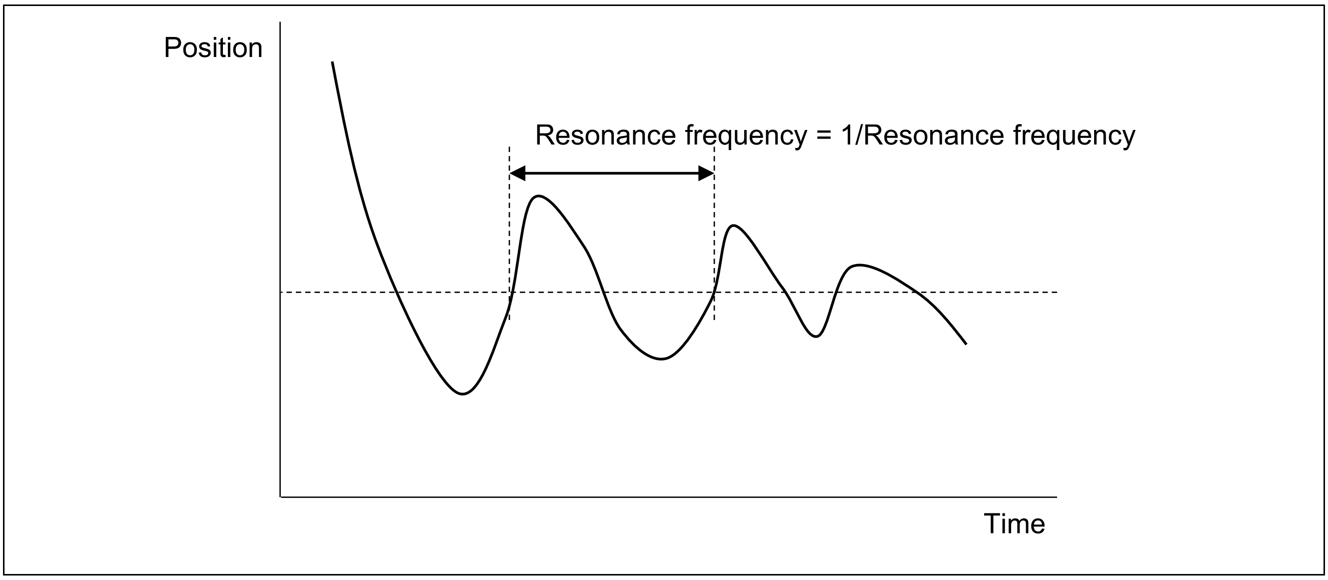


Figure 3-2 Confirmation of Resonance Frequency by Monitoring the Speed Signal

The specifications of the arguments in the R_MTR_SRFOC_SetTorqFilterParam function are as follows:

- Function name: R_MTR_SRFOC_SetTorqFilterParam
- Input:
  (uint8_t) id: Motor ID
  (uint8_t) no: Filter number
  (uint8_t) type: Filter type (0: No filter, 1: First-order lag filter, 2: Notch filter)
  (float) freq: Frequency [Hz]
  (float) q1: Q1 value
  (float) q2: Q2 value

The resonance suppressing filter consists of five stages and the parameter settings are reflected in the filter of the specified filter number. Determine the parameters of the filter with reference to the guideline for setting the parameters, which is shown in Table 3-1.

Table 3-1 Guideline for Setting of Resonance Suppressing Filter

Setting Item (Argument)	Resonance Frequency is Lower than 500 Hz	Resonance Frequency is 500 Hz or Higher
id	MTR_ID_A	
no	Starting from 1, specify a number in order.	
type	2 (Notch filter)	1 (First-order lag filter)
freq	Resonance frequency [Hz]	400
q1	1	0
q2	10	0

In the case of multiple resonance frequencies, specify the filter number with the “no” parameter and construct a multistep resonance suppressing filter.

If multiple resonances at resonance frequencies of, for example, 100 Hz, 300 Hz, and 900 Hz, writing the following code in software configures a resonance suppressing filter that consists of 100-Hz and 300-Hz notch filters and a 400-Hz first-order lag filter, and this filter is capable of suppressing the mechanical resonances.

R_MTR_SRFOC_SetTorqFilterParam(MTR_ID_A, 1, 2, 100, 1, 10);

```
R_MTR_SRFOC_SetTorqFilterParam(MTR_ID_A, 2, 2, 300, 1, 10);
R_MTR_SRFOC_SetTorqFilterParam(MTR_ID_A, 3, 1, 400, 0, 0);
```

3.2 Demonstrations by GUI

After tuning of the demo system has completed, proceed with training in the demo system by running the demonstrations. Figure 3-3 shows a general flow up to the point of running the demonstrations.

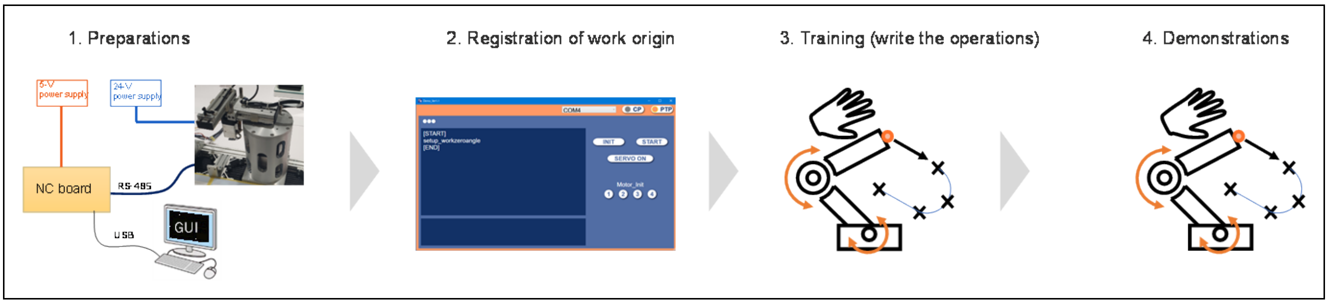


Figure 3-3 General Flow up to Demonstrations

3.2.1 Preparations

Prepare for operation using the following procedure. See section 1.3, NC Board, for the specifications for connection to the NC board.

1. Connect the NC board and an emulator and write the NC software (RobotArm_rx72m.mot) to the NC board.
2. After software has been written, disconnect the emulator from the NC board and connect the NC board to the PC with a USB cable.
3. Start the GUI up in the PC (see section 1.6).

3.2.2 Registration of Work Origin

Set the coordinates to serve as a base (work origin) before training. The work origin is registered with the procedure shown in Figure 3-4. The work origin absolutely needs to be set when power is turned on but this manipulation can be skipped by saving the contents of the setup_workzeroangle command in a text file and reading the text file containing the command contents when power is turned on.

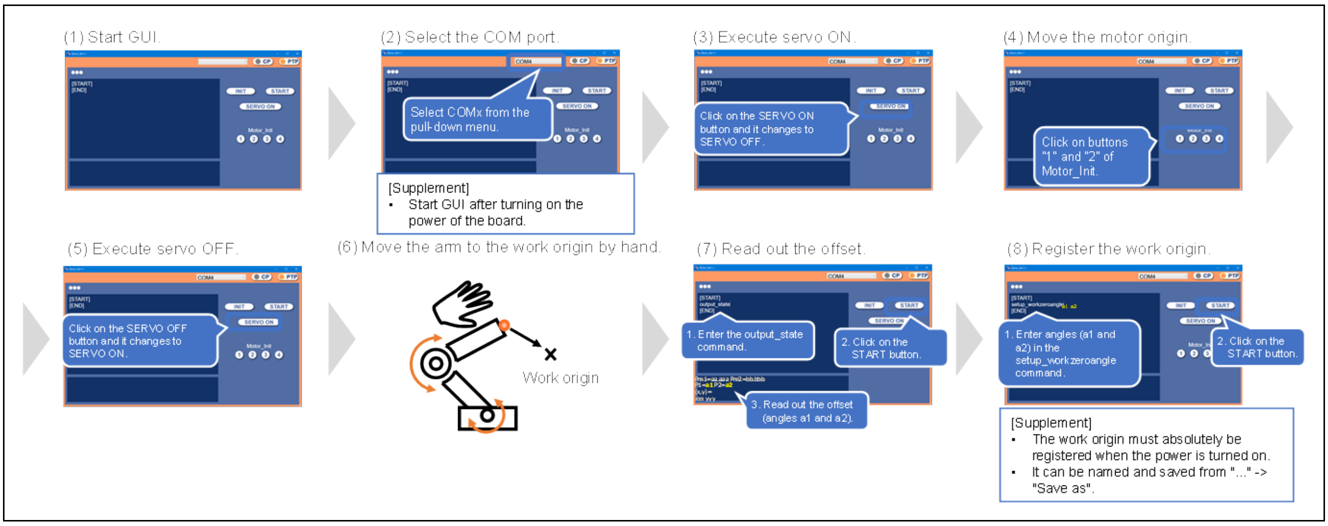


Figure 3-4 Procedure for Registering the Work Origin

3.2.3 Training

Training is handled by the procedure shown in Figure 3-5. Move the arm to a desired point by hand, read the coordinates by executing a command in the GUI, and then write the desired operations based on the coordinates that were read out.

Saving the input command in a text file allows omission of the trouble of re-training by reading the text file from the next time. Note that the application note "R01AN5662EJ0100". provides a reference to the usable commands.
For reference, Figure 3-6 shows an example of training to move through the shape of the numeral 8 and Figure 3-7 shows a training example for moving through the shape of the letter M.

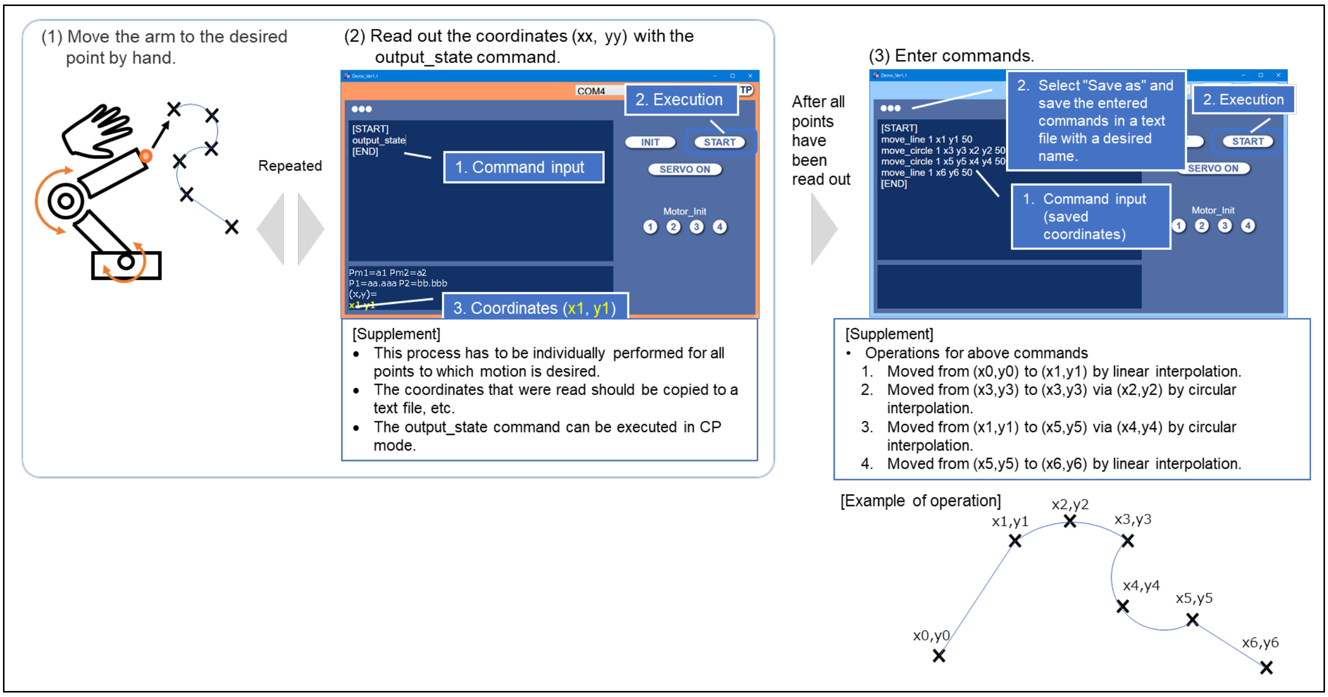
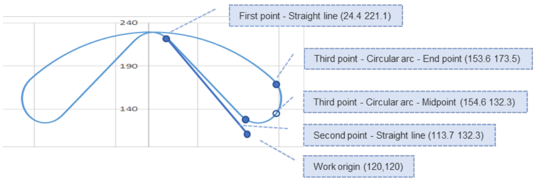


Figure 3-5 Training Procedure

Example: Trajectory operation of numeral 8



1. Use the output_state command to read out the coordinates (xn, yn).
2. Coordinates can be displayed to the thousandths-place digits without change (tenths-place digits are used in the example to the right).
3. For a circular arc, take care not to reverse the order of the end point and midpoint.

First point → move_line 1 24.4 221.1 50
Second point → move_line 0 113.7 132.3 50
Third point → move_circle 0 153.6 173.5 154.6 132.3 50

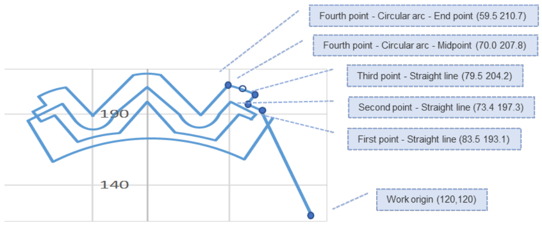
```
[START]
move_line  1 24.4 221.1 50
loop_start  3
setup_motorspeed  70
move_wait  300
move_line  0 113.7 132.3 50
move_circle  0 153.6 173.5 154.6 132.3 50
move_circle  0 5.2 229.3 84.4 214.9 50
move_circle  0 -15.7 221.1 -5.4 227.4 50
move_line  0 -106.5 132.1 50
move_circle  0 -144.7 174.8 -146.8 132.2 50
move_circle  0 4.7 229.5 -74.6 215.5 50
move_circle  1 24.4 221.1 15.1 227.1 50
setup_motorspeed  300
move_wait  300
move_line  0 113.7 132.3 50
move_circle  0 153.6 173.5 154.6 132.3 50
move_circle  0 5.2 229.3 84.4 214.9 50
move_circle  0 -15.7 221.1 -5.4 227.4 50
move_line  0 -106.5 132.1 50
move_circle  0 -144.7 174.8 -146.8 132.2 50
move_circle  0 4.7 229.5 -74.6 215.5 50
move_circle  0 24.4 221.1 15.1 227.1 50
move_line  0 113.7 132.3 50
move_circle  0 153.6 173.5 154.6 132.3 50
move_circle  0 5.2 229.3 84.4 214.9 50
move_circle  0 -15.7 221.1 -5.4 227.4 50
move_line  0 -106.5 132.1 50
move_circle  0 -144.7 174.8 -146.8 132.2 50
move_circle  0 4.7 229.5 -74.6 215.5 50
move_circle  1 24.4 221.1 15.1 227.1 50
loop_end
[END]
```

a: The shape of the numeral 8 is followed once.

■ Explanation of operations
- Moves to the first point (initial speed setting).
- Motor speed setting: 70 mm/s
- Waits for 300 ms.
- Drawing of numeral 8 (first time)
- Motor speed setting: 300 mm/s
- Waits for 300 ms.
- Drawing of numeral 8 (second and third times)
- Repeats the part enclosed between loop_start and loop_end for three times.
- Stops before waiting (end flag = 1).
- Acceleration or deceleration time for all commands = 50 ms

Figure 3-6 Training for the Trajectory of Numeral 8

Example: Trajectory operation of letter M



1. Use the output_state command to read out the coordinates (xn, yn).
2. Coordinates can be displayed to the thousandths-place digits without change (tenths-place digits are used in the example to the right).
3. For a circular arc, take care not to reverse the order of the end point and midpoint.

[Example: Letter M operation.txt]

First point → move_line 1 83.5 193.1 50
Second point → move_line 1 73.4 197.3 50
Third point → move_line 1 79.5 204.2 50
Fourth point → move_circle 1 59.5 210.7 70.0 207.8 50

```
[START]
loop_start  2
setup_motorspeed  70
move_wait  100
move_line  1 83.5 193.1 50
move_line  1 73.4 197.3 50
move_line  1 79.5 204.2 50
move_circle  1 59.5 210.7 70.0 207.8 50
move_line  1 39.3 189.5 50
move_line  1 9.8 218.0 50
move_circle  1 -10.3 217.9 -0.6 219.0 50
move_line  1 -40.1 189.3 50
move_line  1 -60.0 209.2 50
move_circle  1 -80.0 202.7 -70.8 206.7 50
move_line  1 -74.7 196.6 50
move_line  1 -84.1 192.0 50
move_line  1 -78.2 185.0 50
move_line  1 -68.1 189.4 50
move_line  1 -51.2 170.5 50
move_circle  1 -20.5 176.8 -35.7 174.8 50
move_line  1 -0.1 199.0 50
move_line  1 20.4 177.2 50
move_circle  1 50.2 171.6 35.2 174.9 50
move_line  1 67.4 190.1 50
move_line  1 76.5 186.7 50
move_line  1 79.8 190.0 50
move_line  1 61.3 199.0 50
move_line  1 53.1 190.5 50
move_circle  1 23.8 189.8 37.7 180.6 50
move_line  1 -0.1 209.4 50
move_line  1 -24.5 189.9 50
move_circle  1 -52.9 185.5 -37.0 179.5 50
move_line  1 -62.5 197.6 50
move_line  1 -87.8 185.6 50
move_line  1 -69.5 156.4 50
move_circle  1 71.3 158.1 0.1 173.0 50
move_line  1 92.3 187.5 50
setup_motorspeed  150
move_wait  100
 (Note: Write this part.)
loop_end
[END]
```

■ Explanation of operations
- Motor speed setting: 70 mm/s
- Waits for 100 ms.
- Drawing of letter M (first time)
- Motor speed setting: 150 mm/s
- Waits for 100 ms.
- Drawing of letter M (second time)
- Repeats the part enclosed between loop_start and loop_end for two times.
- Stops every time a command is executed (end flag = 1).
- Acceleration or deceleration time for all commands = 50 ms

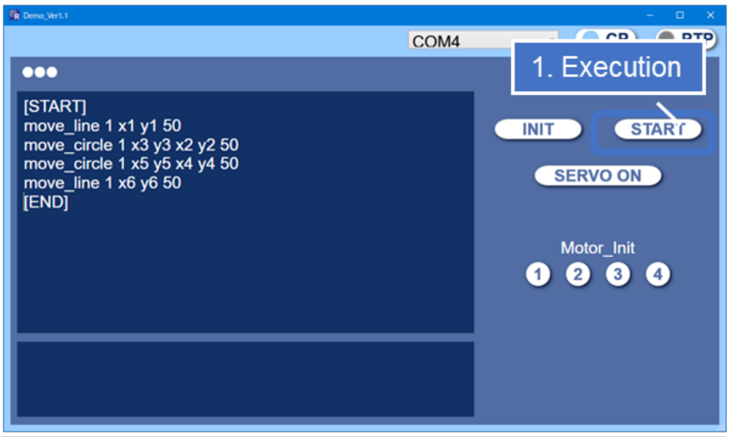
Note: The shape of the letter M is followed once.

Figure 3-7 Training for the Trajectory of Letter M

3.2.4 Demonstrations

The demo system can execute the training operations with the method shown in Figure 3-8. Another method is to read a text file to which the training contents have been written in advance, as shown in Figure 3-9.

(1) Demonstrations



[Supplement]

- Operations for above commands
  1. Moved from (x0,y0) to (x1,y1) by linear interpolation.
  2. Moved from (x3,y3) to (x3,y3) via (x2,y2) by circular interpolation.
  3. Moved from (x1,y1) to (x5,y5) via (x4,y4) by circular interpolation.
  4. Moved from (x5,y5) to (x6,y6) by linear interpolation.

[Example of operation]

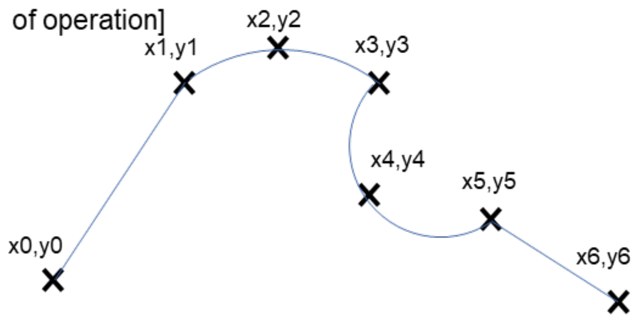


Figure 3-8 Method of Demonstrations

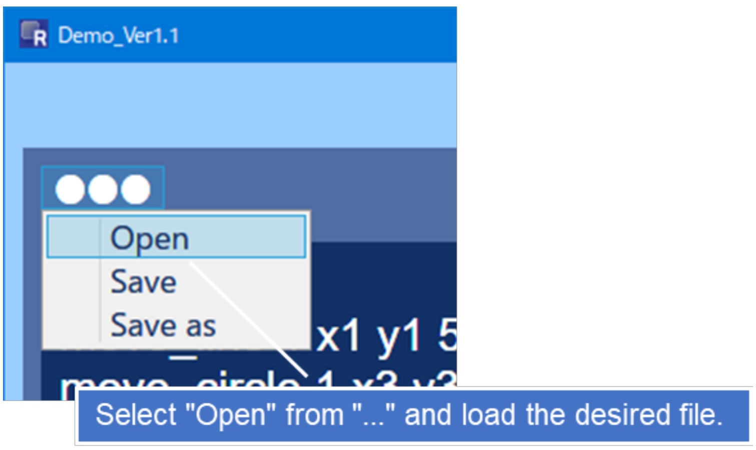


Figure 3-9 Method by Reading a Text File

3.3 Usage Notes

- Since the GUI and NC software do not have fail-safe functions or functions for preventing accidents or defects, the user needs to implement functions for ensuring safety as required.
- The NC software is not capable of determining the cause of malfunctions or an unexpected stop of operation. In such a case, issue a reset.
- When using the move_xxx command to stop operation, setting the end flag to 0 makes the motor operate with acceleration = ∞, so vibration will occur. The position is shifted from the specified coordinates if operation is stopped in such a manner. Therefore, the end flag should be set to 1 when operation is to be stopped.
- When combining the move_xxx commands to change the traveling direction, setting the end flag to 0 makes the motor operate with acceleration = ∞ and vibration will occur. Therefore, when combining operations (for example, continuous operation such as straight line ↔ arc or arc ↔ arc) while the end flag is set to 0, make the direction be changed smoothly.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Jan 22, 2021	—	First edition issued

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)

   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.
2. Processing at power-on

   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.
3. Input of signal during power-off state

   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.
4. Handling of unused pins

   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.
5. Clock signals

   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.
6. Voltage application waveform at input pin

   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).
7. Prohibition of access to reserved addresses

   Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.
8. Differences between products

   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

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