Development of 3 D.O.F parallel robot's simulator for education

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Abstract: In this paper, it is developed simulator system of 3 D.O.F parallel robot for educate of expertness. This simulator system is composed of three parts – 3 D.O.F parallel robot, controller (hardware) and software.
First, basic structure of the robot is 3 active rotary actuator that small geared step motor with fixed base. An input-link is connected to this actuator, and this input-link can connect two ball joints. Thus, two couplers can be connected to the input-link as a pair. An end-plate, which is jointed by a ball joint, can be connected to the opposite side of the coupler. A sub-link is produced and installed to the internal spring, and then this sub-link is connected to the upper and bottom side of the coupler in order to prevent a certain bending or deformation of the two couplers. The robot has the maximum diameter of 230 mm, 10 kg of weight (include the table), and maximum height of 300 mm.
Hardware for control of the robot is composed of computer, micro controller, pulse generator, and motor driver. The PC used in the controller sends commands to the controller, and transform signals input by the user to the coordinate value of the robot by substituting it into equations of kinematics and inverse kinematics. A controller transfer the coordinate value calculated in the PC to a pulse generator by transforming it into signals. A pulse generator analyzes commands, which include the information received from the micro controller. A motor driver transfer the pulse received from the pulse generator to a step motor, and protects against the over-load of the motor
Finally, software is a learning purposed control program, which presents the principle of a robot operation and actual implementation. The benefit of this program is that easy for a novice to use.
Developed robot simulator system can be practically applied to understand the principle of parallel mechanism, motors, sensor, and various other parts.

Keywords: Parallel robot, Simulator, Inverse-kinematics, GUI software program

1. INTRODUCTION

A parallel structure mechanism has been applied to variety field as haptic device, pilot's flight training, simulation entertainment device, driving training in the last decade. The reason for this is that it has a small size, is precise, and can implement a flexible and stable operation due to the distribution of a heavy weight compared to that of a serial device. In addition, it has the merit of a fast working speed. Parallel structured devices, which have these merits, have been actively utilized for application in a number of medical techniques and all-purpose factory automations.

The concept of parallel mechanism was proposed by Stewart for flight simulation of aircraft, named STEWART PLATFORM in 1965[1]. Its structure had been consisted by 6 SPS joints (Spherical, Prismatic, Spherical joints) between Base and End-effecter, controller by 6 prismatic actuators. The kinematics solution of parallel structure has been proposed by Hunt in 1978[2]. From proposed kinematics solution method, it had been studied to many researchers for structure feature, mathematics solution and application of a parallel [3-5].

A new type of parallel mechanism has been developed since the conventional Stewart platform in the late 1980s. In 1988, DELTA robot with 3 rotary actuators, were developed by Clavel. This DELTA robot is going on practical and a theoretical study until now [6-9].

Although many studies on these new mechanism have been published, and although they present a number of merits compared to that of a serial device, these new mechanism are limited in their application due to a limitation of design, difficulties in mathematical analysis, and some other problems.

In particular, it is more difficult to develop an educational purpose robot due to these problems.

Due to the existence of technical difficulties, this study is focused on developing an educational purpose robot simulator. This simulator consists of a three degrees-of-freedom parallel robot, robot controller, and operation program. First, the parallel mechanism has a three degrees-of-freedom rotary actuator, which consists of three geared step motors, and is designed and produced using a three dimensional program. Because a geared step motor is able to control the position of a robot without any additional devices, it has the merit of being able to produce a robot with light weight and a small sized dimension. The robot produced in this study has the maximum diameter of 230 mm, 10 kg of weight (include the table), and maximum height of 300 mm.

Second, the produced controller consists of a PC, micro-controller, pulse generator, and step motor driver. Devices used in this study were configured as single units except for the PC used by everyone. In addition, the controller was equipped with a safety device and circuit to protect the robot and circuits.

Finally, the program (software) used in this study inputs signals to the robot, and is designed to set various parameters. The signal input used by this program can be implemented using a mouse or keyboard, and all users are able to easily use this program. In addition, a user can develop a new program using the supplied input functions.

This educational purposed parallel robot simulator described previously can be practically applied to understand the principle of parallel mechanism, motors, sensors, and various other parts.

2. MODELING AND INVERSE KINEMATICS

2.1 Inverse Kinematics

Inverse kinematics is very complex. To find a solution of inverse kinematics it used geometric method at a link in this paper. To solve inverse kinematics, a length and joint angle of the one link is displayed by Fig. 1

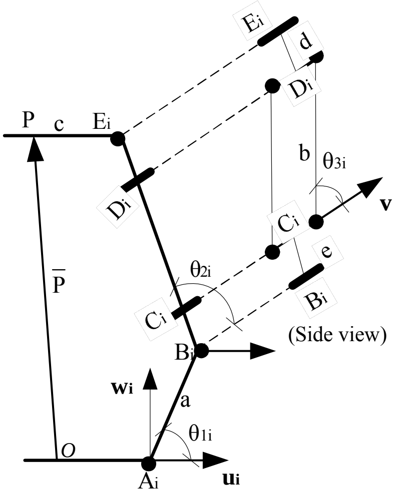

Fig. 1 Coord. and length of the robot

Rotate quantity of motor θ_{1i} is written as

$$
\begin{aligned}
a \times \cos(\theta_{1i}) + b \times \sin(\theta_{3i}) \times \cos(\theta_{1i} + \theta_{1i}) &= c_{\xi} \\
a \times \sin(\theta_{1i}) + b \times \sin(\theta_{3i}) \times \sin(\theta_{1i} + \theta_{2i}) &= c_{zi}
\end{aligned}
\qquad (1)
$$

Expanding Eq. (1), we obtain

$$
\begin{aligned}
a\cos\theta_{1i} + b\sin\theta_{3i} \bullet \cos\theta_{1i} \bullet \cos\theta_{2i} - b\sin\theta_{3i} \bullet \sin\theta_{1i} \bullet \sin\theta_{2i} &= c_{\xi} \\
a\sin\theta_{1i} + b\sin\theta_{3i} \bullet \sin\theta_{1i} \bullet \sin\theta_{2i} - b\sin\theta_{3i} \bullet \cos\theta_{1i} \bullet \sin\theta_{2i} &= c_{zi}
\end{aligned}
\qquad (2)
$$

Expanding Eq. (2), we obtain

$$
\begin{aligned}
\cos\theta_{1i} \bullet (a + b \bullet \sin\theta_{3i} \bullet \cos\theta_{2i}) - b\sin\theta_{3i} \bullet \sin\theta_{1i} \bullet \sin\theta_{2i} &= c_{\xi} \\
\sin\theta_{1i} \bullet (a + b \bullet \sin\theta_{3i} \bullet \cos\theta_{2i}) - b\sin\theta_{3i} \bullet \cos\theta_{1i} \bullet \sin\theta_{2i} &= c_{zi}
\end{aligned}
\qquad (3)
$$

Eq. (3) can be written by θ_{1i}

$$\sin\theta_{1i} = \frac{B \bullet C - A \bullet D}{-B^2 - A^2} \qquad (4)$$

$$\therefore \theta_{1i} = \sin^{-1} \frac{B \bullet C - A \bullet D}{-B^2 - A^2} \qquad (5)$$

where, $A = a + b \bullet \sin\theta_{3i} \bullet \cos\theta_{2i}$, $B = b \bullet \sin\theta_{3i} \bullet \sin\theta_{2i}$

$C = c_{\xi}$, $D = c_{zi}$

2.2 Structure of the robot

The structure of the robot used in this study is as follows. This robot has a rotary actuator, which consists of three geared step motors, on a fixed base plate. These motors are used for the purpose of deceleration, high torque, and high resolution. In addition, because these motors have a high torsional stiffness, they are hardly effected by changes in load torques. It is also easy to control the position and speed without any additional equipment. Table 1 is specification of the geared-step-motor.

Table 1 Specification of the actuator

Item	Value
Model	PK243A2-SG18
Torque(kg• cm)	8
Current(A/phase)	0.4
Voltage(V)	9
Velocity	0 ~ 100
Step	0.1
Reduction Ratio	1 : 18

An input-link is connected to this actuator, and this input-link can connect two ball joints. Thus, two couplers can be connected to the input-link as a pair. An end-plate, which is jointed by a ball joint, can be connected to the opposite side of the coupler. In addition, a sub-link is produced and installed to the internal spring, and then this sub-link is connected to the upper and bottom side of the coupler in order to prevent a certain bending or deformation of the two couplers. Fig. 2 shows the structure and coordinate of the proposed parallel robot

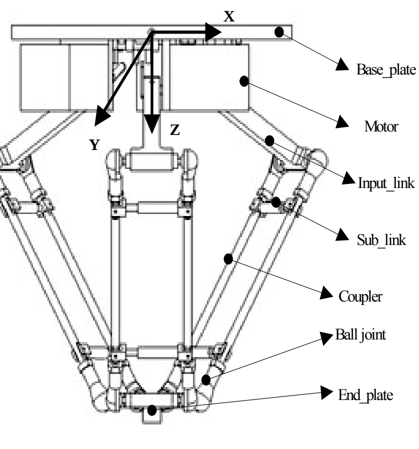

Fig. 2 Structure and coordinate of the parallel robot

The robot was produced using an aluminum alloy steel, except for the motor and ball joint, to reduce the weight. Table 2 is mechanical specification of the robot.

Table 2 Specification of the robot

Item			Unit	Value
Dimension	Body	Base-plate	mm	Φ210x9
		Base-cover		Φ220x9
		Coupler		Φ6x166
		Input-link		12x12x95
		Sub-link		9x7x57
		End-plate		70x60x9

	Actuator	Motor		42x42x94
		Ball joint		35x17x31.7
	height	Max.	mm	300
		Min.		180
Weight	Total Weight (include table)		kg	10
	Motor			0.35
	Max. Load			3
	Ball joint			0.024
Mobility	Active DOF		ea	3
	Angle of ball joint		deg	50
	Rotate angle of joint			-5 ~ 70
	Velocity of joint		deg/sec	100 (50000)

3. CONTROL OF THE ROBOT

3.1 Structure of the controller

To operate the robot, controller is composed by PC, Microcontroller, Pulse Generator and Step Motor Driver. Also, all control parts and power supply were integrated as a single unit except for the PC in this paper. Fig, 3 shows internal overview of the control and external overviews of it is shown by Fig. 4.

Fig. 3 The controller – Internal

Fig. 4 The controller – External

As shown in Fig. 4, back part of the controller has connectors to motor and sensor, external I/O connector, RS-232C and USB connector to computer communication. Table 3 is specification of the controller-Robostone

Table 3 Specification of the Robostone

MODEL	RoboStone-Ⅱ (4-Axis)
Input Voltage	220V
User Interface	Serial I/O for PC External I/O Operation
File System	EEPROM(36KByte) Parameter Program Saving
External I/O	16 General Input 8 General Output
Programming(PC,HHP)	Upto 4 Program(512 step)
Max. FREQ. of Pulse Output	6.5Mpps
Max. FREQ. of Encoder Output	1 Mpps
Serial I/O	RS232C(115.2kbps) USB1.0
Encoder Input	Line driver type
Pulse Output	CW/CCW, Pulse/Direction
System Input/Output	+Limit, -Limit, Home, Alarm, Reset, Emergency stop
Interpolation Function	Linear, circulation, Curve
Velocity Control Type	S-curve or Trapezoid Accel. Decel Control
Operating Temperature	0 ~ 40
Extension I/O	1 Mbps

The controller produced in this study exhibited the following characteristics.

① This controller is able to control the position using a shaft.

② This controller supports an easy way to design a system with simple and various parameter functions.

③ It is easy and fast to write a program with various commands.

④ Using an internally installed EEPROM, it is possible to write a program, and is easy to store and change parameters.

⑤ Each axis has its own original point and sensor input.

⑥ This control can be communicated with a PC, and storage, or changes in the parameter are very easy.

⑦ This controller has various and simple communication control functions, and supports an easy update using a self-program method.

The internal structure of the controller previously described will be introduced in the next section.

3.1.1 PC

The PC used in the controller sends commands to the controller, and transform signals input by the user to the coordinate value of the robot by substituting it into equations of kinematics and inverse kinematics. In addition, it can simulate an actual robot using a simulation window of OPENGL.

3.1.2 Microcontroller

A micro-controller transfers the coordinate value calculated in the PC to a pulse generator by transforming it into 8-bit signals. In addition, it illustrates the state of the robot by transferring sensor signals generated by the sensor installed in the robot, or external I/O signals to the PC.

The micro-controller used in this study was a MEGA128, which is an 8-bit controller, and is manufactured by ATMEL. This micro-controller can process high-speed calculation, and has 53 I/Os. In addition, it can output an 8-channel PWM signal. Table 4 is specification of the micro controller.

Table 4 Specification of the microcontroller

	Unit	Value
Flash	Kbytes	128
VCC	V	4.5 – 5.5
SRAM	bytes	4096
F.max	MHz	16
I/O	channel	53
Interrupts		34
Ext. Interrupts		8
16 bit Timer		2
10 bit A/D		8
UART		2
8 bit Timer		2
PWM		8

3.1.3 Pulse Generator

A pulse generator analyzes commands, which include the information received from the micro-controller, such as coordinates, velocity, and acceleration, and simultaneously generates and transfers pulses for the motor. Because this information includes various acceleration and deceleration profiles, it supports a soft and natural rotation.

The pulse generator used in this study was the PCL6045, which can control 4-axis. This pulse generator can output signals to control the step motor at the programmed speed, and performs the control of outputs using a pulse input signal. In addition, the output frequency can be generated at a maximum of 5MPPS (Pulse per Second). Also, this pulse generator performs a number of additional functions, such as velocity override, moving distance override, and Quasi-S shape curve driving. Table 5 is specification of the pulse generator – PCL6045.

Table 5 Specification of the PCL6045

Number of Controllable Axes (ea)	4(X, Y, Z and U)
Reference Clock(MHz	19.6608
Position Control Range	-134,217,718 to +134,217,727
Pulse Rate Setting Step Range	1 to 65,535(16bit)
Acceleration Rate Setting Range	1 to 65,535(16bit)
Counter (ea)	4
Comparator (ea)	5 (28bit)
Supply Voltage (V)	3.3 and 5
Mode Type	Linear/S-curve

3.1.4 Step Motor Driver

A step motor driver transfers the pulse received from the pulse generator to a step motor, and protects against the over-load of the motor.

The driver used in this study was the CSMD2-B440-CE, which is a 2PH micro-step motor driver manufactured by CONVEX. This driver has a high precision rate, about 25 times more than that of the existing half step motor driver. Therefore, it can control a parallel robot very accurately. Table 6 is specification of the motor driver and overview of the motor driver is shown by Fig. 5.

Table 6 Specification of the CSMD2-B440

Input Voltage	DC 15 ~ 36 V
Output Current	2A/Phase
Excitation	Constant Current PWM Bipolar
Resolution	200 - 50000
Max Input Pulse FREQ	500kHZ
Control in Signal	Alarm reset, motor free
Control Out Signal	Alarm out or Timing Photocoupler isolation

Fig. 5 2PH micro step motor driver

3.2 Sensor System

This study produced the robot implemented in the investigation guarantee a stable operation to achieve this stability sensors were installed to protect it from certain dangers, which may occur during the operation of the robot. The sensor used in this robot was the BS5-L2M, which is a photo-micro-sensor produced by AUTONICS. It has a micro-scale size, and is easy use with an internal amp. The specification of this sensor is summarized by Table 7

Table 7 Specification of the photo sensor

Model		BS5-L2M
Response distance	mm	5
Response method		penetrated
Response body		0.8x1mm
Power Supply	V	5 – 24 DC
Consumption current	mA	30
Control output		NPN Open collector
Response Time	us	Input 20 Output 100
Response Frequency	kHz	2
Mater		PBT
Weight	g	30

The sensor was fixed on the base plate, and it can make the system stop immediately when the load exceeds the device's operational limitations. In addition, it can support a forced stop for an emergency state, even though the system under operation.

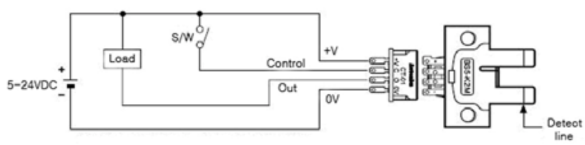

Fig 6 Connection of photo sensor

Fig. 7 shows the developed 3 D.O.F parallel robot and controller.

Fig. 7 Robot and Controller

4. SOFTWARE

4.1 Introduction of the software

Finally, the last element of the robot is a learning purposed control program, which presents the principle of a robot operation and actual implementation. This program displays the robot operation commanded by the user using a 3D simulator built by the OpenGL program. Thus, the user can identify both the operation in each axial joint and possible collisions of the robot using this display. In addition, this program implements some kinematics and inverse Kinematics, and produces them as a DLL file. Using this program, it is possible to control the function defined in this system in any other multi-joint robots by modifying the internal equations.

4.2 Structure of the programs

The program, which was used to control the robot, used a MDI (Multi-Document Interface) method. This program is configured as a single display mode, which presents all of the windows displaying the operation. The benefit of this program is that easy for a novice to use. The program developed in this study consists of six tab buttons to configure the operation and parameters.

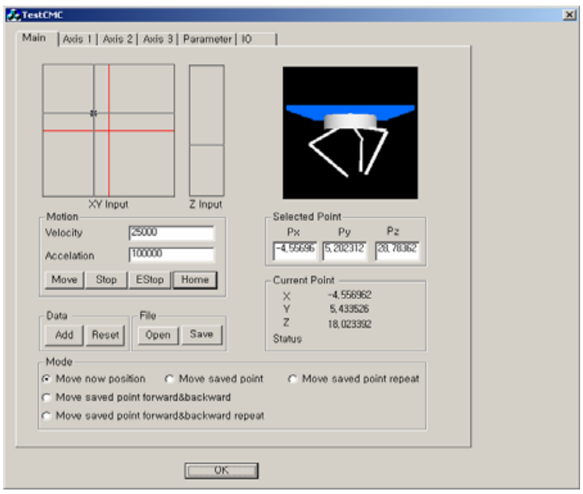

Fig. 8 Main window of the software

Fig. 8 shows the main window of developed program. There are five different modes to operate the robot, and the operation can be implemented by pushing the given radio buttons. Graphic simulation windows using OpenGL are located at the upper side of the simulation window. In addition, an input window, which can locate a specific robot position on the axes of X, Y, and Z by selecting it with a mouse cursor, is located at the left side of the input window.

The three Axis tabs of the second, third, and fourth one present the state of the three axes as presented in Fig. 9.

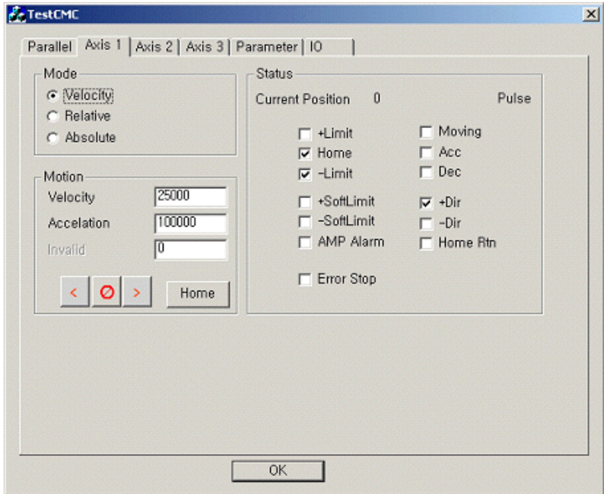

Fig. 9 Condition set window of the Axis1

As shown in Fig. 9, this program has three different modes for each axis, such as velocity, relative, and absolute mode, and can identify whether or not the input exists from the sensor of Limit, Home, and Alarm.

The 5th tab is a window, which configures various parameters of the robot, as presented in Fig. 10, such as the moving speed of the robot, acceleration/deceleration time in an interpolation process, maximum speed, and various other parameters.

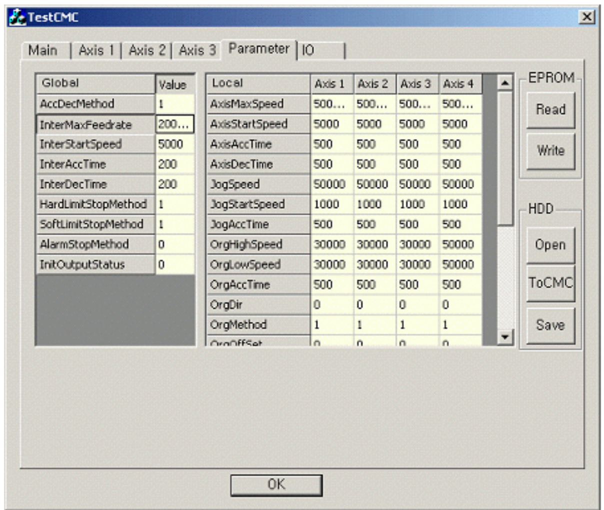

Fig. 10 setting window of parameter

The I/O tab, which is the last tab, verifies the state of the external I/Os. Fig. 11 presents the connection of the input and output to the external side.

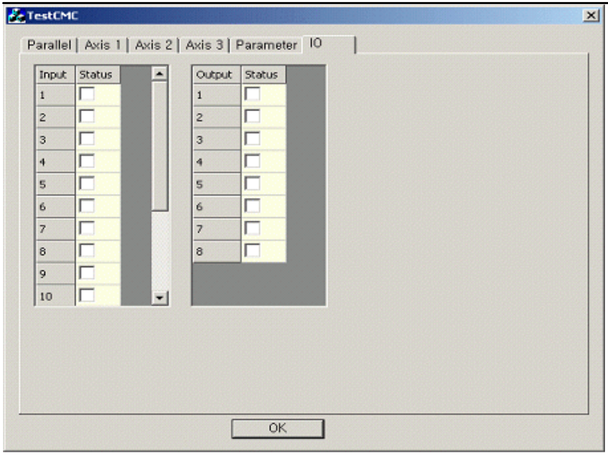

Fig. 11 External I/O resister pin

5. CONCULSION

Although there are many educational sources regarding robots in Korea, such programs suffer from an educational deficiency, due to the use of a commercial robot. This study developed an education purposed simulator, which is a parallel robot with three degrees of freedom. This study drew the following conclusions.

1. A double link structure was used to protect against deformation of appliances, and which minimized the length of links. In addition, this study produced a small parallel robot, which had light weight and high stiffness, using aluminum.
2. This robot can be precisely and smoothly operated using rotary actuators, which consist of step motors, where the actuators are controlled using a micro-step method.
3. The developed controller with various external I/O ports can be applied to various educational fields, such as electric/electronics, control, CAD, micom, and automation.
4. The developed software is characterized by easy-to-use Windows-based GUI interfaces, and presents the most accurate structure for education and practice.
5. By developing the software as an all-purpose product, it is possible to apply this program to certain multi-joint robots and other mechanical systems.

6. UNITS AND SYMBOLS

6.1 Units

In the paper, all authors are required to use the SI unit.

6.2 Symbols

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the contribution of Korea Industrial Technology Foundation (KOTFT).

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