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Development of Embedded Robot Controller for Shipbuilding

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Abstract: This paper describes a development of a small and high-performance embedded controller system in order to apply it to a robot system for improving productivity in shipbuilding. The development of such an embedded controller was performed as a coherent design and development through applying a digital signal processor. The product developed in this study consists of a CPU board including vision functions, motion and driver boards for servo motor controls, and input/out and power board. Also, various communication protocols were implemented in the development process by considering their expansibility and flexibility. In addition, a robot controller system was developed to communicate external robot operation systems as a manner of wired and wireless communication. Furthermore, this study performed functional and environmental tests to verify the stable operation of such a robot controller under internal or external poor working conditions.

1. INTRODUCTION

In recent years, a certain trend in automatic systems that aims small and embedded automatic systems has been conducted in various industrial fields through high-performances and various types in electronic parts. Also, this trend represents no exceptions in robot industries. In general, the term of an embedded system can be expressed as "those used to control specialized hardware in which the computer system is installed". It means that this system is a type of control system that controls specific hardware and is designed to perform specific works and functions with an internal microprocessor in which this system does not depend on other systems.

Automation in shipyards has been rapidly conducted to improve productivity in shipbuilding processes, such as cutting, welding, and painting, and that represents a major trend in production automation using robots. The shipbuilding is processed as a double hull structure and block unit production and that is to be integrated in a dock. Because this production process has lots of repetition works in limited spaces, a light weight in devices for the aspect of mobility and certain handling easiness in controller boxes and cables in production automation processes with robots become important factors in productivity.

A large part of conventional industrial purposed robots have been used their controllers at separated places according to the increase in weights and volumes because such robots show an increase in the complexity of controllers and precision control of motors in order to perform various functions. In the application of robots in a ship block, their controllers are installed at an external place due to the large scale of volume in which the application of long cables between the robot and the controller causes various problems in such working conditions. The weight of cables may cause certain industrial accidents, and the preparation and rearrangement of cables require lots of working hours and that decrease productivity. In addition, cables in such working places show frequent damages and that also require lots of repairing and maintaining hours.

In order to improve the easiness and productivity of workers in a shipyard, mobile robots including fixed type robot systems that make possible to process specific works with two or less workers have been used as a type of mobile robot in the present time. The mobile robot has a function of attached driving on floor or vertical plane and can be used in various works, such as welding, cleaning, inspection, and painting. Also, it is possible to build a lightweight controller for this robot through applying a small-embedded type controller.

It is important to develop an embedded type controller that satisfies stable operations in limited and poor environments, such as narrow space, heat, and noise, due to the lightweight and small size of robots. This study developed a controller that is to be applied as a standard type according to the type of controller boards in order to develop proper mobile robot controllers for different work places.

The individual modules used in this embedded controller system were developed based on their functions. These modules were developed using a digital signal processor (DSP) as a common device. The product developed in this study consists of a CPU board including vision functions,

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motion and driver boards for servo motor controls, and input/out and power boards. Also, various communication protocols were implemented in the development process by considering their expansibility and flexibility. In addition, this study performed functional and environmental tests to verify the stable operation under internal or external poor working conditions.

This paper attempts to describe general ideas on the development of an embedded controller for the automation of mobile robots in the production automation in a shipyard.

2. IMPLEMENTATION OF THE CONTROLLER

In the design of the embedded controller, it is necessary to consider its size and that is to be determined as a small size. Also, a modulization in design it to be regarded by extending their capacity for future requirements compared to that the application that uses a single device or element. The main boards used in an embedded mobile robot controller can be largely classified as CPU, 8-channel motion board, AC servo-motor driver board, and several sensor and communication display devices. Fig. 1 illustrates the hardware and communication system used in an embedded controller.

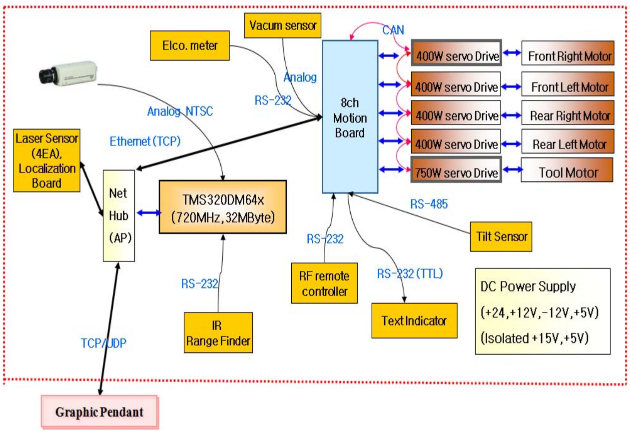

Fig. 1. Block diagram of an embedded robot controller

The CPU board (including vision) used in the controller is used to watch the front and rear of a robot, recognition of the surface after finishing specific works, and avoid certain obstacles. In order to perform the vision function included in a CPU, the controller was designed using a CPU (5760 MIPS, TMS320DM642, Texas Instrument) to implement fast speed and enough memory (32 Mbytes). The controller applies the image signal read from an analogue camera (NTSC type) to the CPU through an image processing ADC in which the processor includes exclusive image processing devices and that masks possible to design a low power consuming design due to small elements and small size compared to other processors.

The motion board used in the controller analyses the commands from the primary controller and transfer the information, such as position and speed, to the servo driver board. Also, CAN communications are used between the servo driver and the motion board to determine contact point signals for the servo state input and output data, clock signals that include position and speed information, servo states that represent lower levels than the contact point signals, and control values in servo controls.

In the development of the servo driver board, the servo motor used in the control was selected as a type of permanent magnetic synchronous motor(PMSM) that represents excellent controllability and environmental resistance. Because of the characteristics of embedded controllers, it avoided the power and configuration devices used in conventional products in order to implement a small-scaled servo driver and that was designed as a manner that commonly uses several servo drivers. In the case of the encoder that determines the position of the applied PMSM, a 17-bits protocol type encoder was used to perform small wiring works and easy maintenance. Also, the servo driver is able to control up to 750W class servo motors in which the control can be performed by the limitation of specific encoder resolution. In addition, the heat generated from this device becomes a very important factor because the electric energy is transformed into high-powered mechanical energy. In order to perform a small-sized servo driver, heat sinks were designed at the lower section of the controller box designed in this study that is different from conventional servo drivers, which include heat sinks or fans.

Finally, the I/O & power boards are used in various functions in the system, such as the communication between robots, contact points, analogue sensor inputs, actuation of solenoid valves, and indicator display. The communication method supports various types, such as USB, RS-232, RS-485, CAN, and Ethernet. Also, the contact points support isolated 24V input, TTL output, 10V and 5V analogue inputs, and relay contact point output. Table 1 shows the specification of the boards used in the embedded robot controller.

Table 1. Board specification of the embedded robot controller

Board	Specification
CPU & Vision board	• NTSC vision In 2-ch., Out-1Ch. • 100Mb Ethernet • Size: 150 x 100 mm • TMS320DM642 (5760MIPS) • 32M RAM, 2M Flash
Motion board	• TMS320F2812 used, 8-axis available • X7083 motion chip controller used • Size: 150 x 100mm • UDP, CAN, RS232 comm. Protocol • Sine, parabolic, linear motion adapted

Servo driver board	• PMSM motor adapted • Size: 100 x 70 x 43mm • Absolute/Incremental encoder used • 50W ~ 750W Capa., 12.5kHz scan time
I/O & Power board	• DIM: 150 x 100 mm • ADC: 10V,5V 8 channel • DIN/OUT: Isolated 4pts, 4 relay • CAN, RS232, RS485, USB, Ethernet

3. DEVELOPMENT OF AN EMBEDDED CONTROLLER

3.1 CPU board

In the design of the CPU board that focuses the easiness of the development process, such as small size and low power consumption, the CPU board was designed to install a small-scaled vision board that is to be installed in the CPU board and processes calculation functions in a robot controller including high performance image processing functions. Therefore, the processor TMS320DM642 with the fast speed of 5760MIPS that has a special device for obtaining digital images was used in this board. In order to perform fast response, a relatively tough conventional and commercial OS was not applied. Also, the firmware was operated using the interrupt and task that are optimised to perform its image obtaining process and driving algorithm. In addition, the development of the firmware was achieved by connecting a PC and the JTAG using the Code Composer Studio 3.3 by TI. Furthermore, it was designed to upgrade it as a network system for improving future firmware.

To perform a digital vision function, in general, a processor, which has a frequency with more than 100MHz, an analogue-to-digital converter(ADC) that is used to convert analogue images to digital images, and main memory that is able to store minimum 2 frames in order to apply FIFO memory image processing corresponding to the synchronization of image frames are required. The processor TMS320DM642, which is optimised to process images, is a type of DSP and that includes synchronization signals generated from the video port, which is an exclusive ADC, inside the processor and the CCIR656 digital image signal decoder in order to simply configure desired circuits without any specific synchronization signals and image processing buffer memories. Also, this DSP includes an EMAC (Ethernet Media Access Controller) and MDIO (Management Data Input/Output) module to perform Ethernet communication by attaching an Ethernet layer at the external side.

The importance of the ethernet in an image processing board is that although the image processing results are generally required to transfer to the next system, certain cases are required to transfer all processes in such image processing results because it contains huge amounts of data based on the characteristics of digital images. The previously described CPU board includes such an image processing function and the ADC that represents various input ranges, such as -10 ~ +10V and -5 V ~ +5V, and that includes a CAN controller and UART controller in order to response for various other surrounded communications.

As shown in Fig. 2, the CPU board used the interrupt and task to implement simplicity and real-time without using a commercial OS. It demonstrated that the function of video capture, video display, and IRF(Infrared Range Finder) are processed in the interrupt, driving algorithm and network processing are processed in the task.

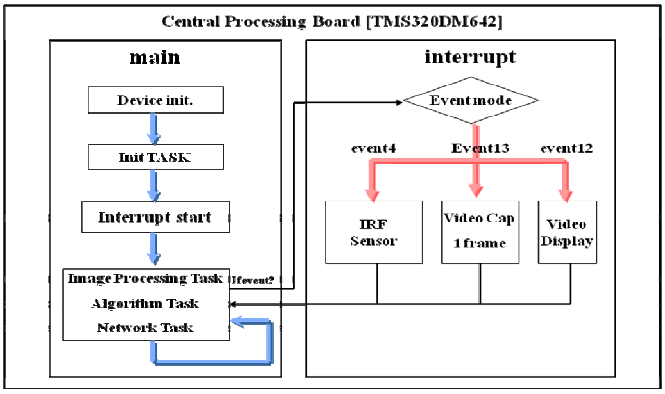

Fig. 2 Block Diagram of the CPU board firmware including an image Processing Module

Fig. 3 shows that a small-sized vision board is installed at the left and lower side of the developed CPU board.

Fig. 3 CPU board including the Image Processing Module

3.2 Motion board

A motion board is used to control several servo drivers because a host controller represents certain difficulties in their control performance of several servo drivers even though it is able to directly control a servo driver. Because the motion board used in this system analyses the command from the primary controller, it can be applied to a simple control process and to an independent control system because it includes a related process.

The motion board fabricated in this study was connected to the host controller through an Ethernet system and to the lower part, i.e., the servo driver, through the CAN communication. It can transfer not only the command executed from the primary controller, but also the state and major variables obtained from the primary controller by integrating such data in the motion board as a manner of real-time to the primary controller. Also, it is able to display the present state of applied robots using an exclusive display device. The motion board has the advantage that it includes a high-performance DSP and it does not require various sensor values and contact points in robots and communication (CAN, RS232, RS485, and Ethernet) including extra I/O devices at the external side. Fig. 4 illustrates the functional diagram of the motion board. Fig. 5 shows the image of the motion board developed in this study.

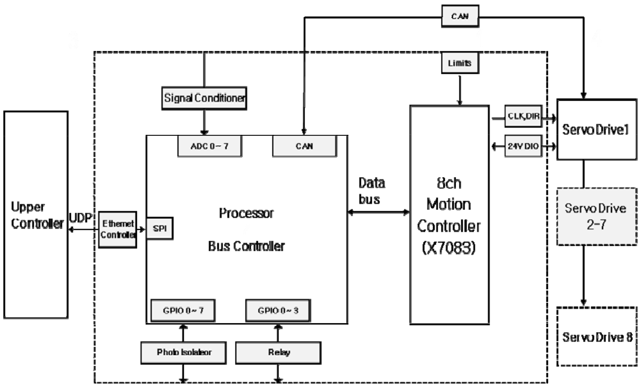

Fig. 4 Functional block diagram of the motion board

Fig. 5 Picture of smll size 8-axis motion board

3.3 Servo driver board

The servo driver is the most important part in an embedded robot controller and requires enough torque, velocity, and precise position control even though it is able to control a servo driver by calculating data in the primary controller. Thus, studies on the design and development of servo drivers have been largely focused in recent years. A control loop was designed to perform optimal control for speed, current, and torque based on various control variables of the servo driver. Fig. 6 shows the control loop of the servo driver.

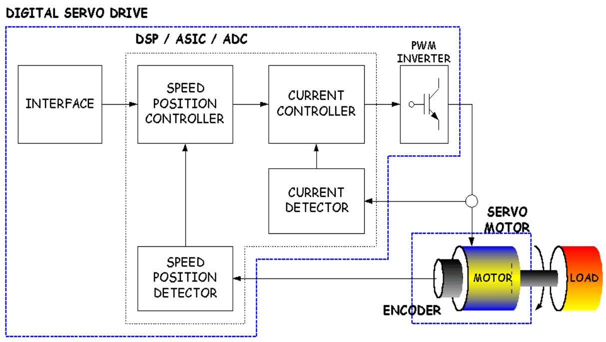

Fig. 6 Diagram of the servo driver control loop

The target servo motor used in this study was selected as a PMSM that represents excellent control characteristics, environmental resistance, and durability. Table 2 notes the specification of this motor.

Table 2. Specification of the target motor

Parameter	Value	
Phase/ Pole	3 phase / 8 pole	
Output	400 W	750 W
Rotor Inetia	0.34[gf*cm*s^2]	1.10[gf*cm*s^2]
Rotation Speed	3000 rpm	3000 rpm
Rated Torque	1.27 Nm	2.39 Nm
Inductance/Phase	8mH	8mH
Resistor/Phase	0.8 ohm	0.6 ohm

The PMSM driver was also designed to perform small scale and stability. In order to achieve its small scale, the design was focused on integrated power module, common use and case attaching style of heat sinks, and single design of the control section of the driver based on their axis less than five in which contact point signals were processed through a communication method.

Fig. 7 shows the hardware configuration of the servo driver and that is connected to the power supply, communication and contact point sections for the primary controller, position sensor, voltage sensor, and current sensor with the processor TMS320F2811 as the central figure. Also, the driver section includes the gate driver, motor output section, and surge current protection circuit based on the intelligent power module(IPM). In addition, the control was performed using the following model for the PMSM motor and the voltage equation was produced from this model. Fig. 8 illustrates the image of the AC 400W/750W compatible servo driver developed in this study.

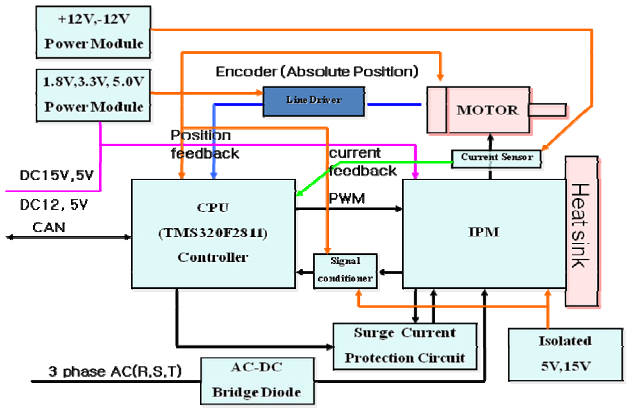

Fig. 7 Block Diagram of the PMSM Servo Driver

Fig. 8 Image of AC 400W/750W compatible servo driver

3.4 I/O & Power supply board

In the design of the input/output & power supply board, the major idea was focused on their small sized design. Thus, it was integrated as a single board. Because all electronic parts require specific power, it is necessary to analyse power requirements in external sensors, server drivers, and motion boards. Then, the results of this analysis was noted as a type of table and that was used to fabricate the board as a small size based on safety coefficients including the table.

Fig. 9 shows various voltages and supplier based on the power supply board.

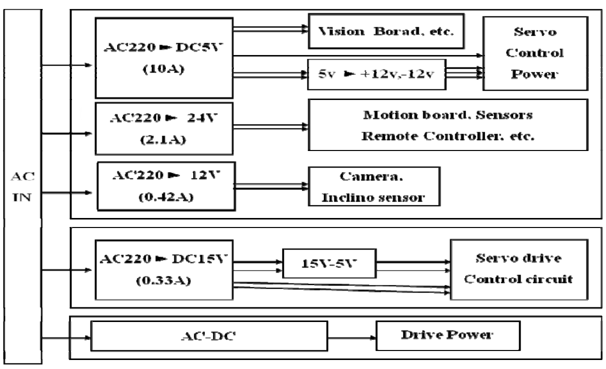

Fig. 9 Various voltage out from power supply board.

In the design of the I/O board, the ethernet communication was used as a basic method in which the I/O specification was varied according to the applied robot. Therefore, a small number of the I/O used the contact point of the motion board and a large number of sensors used in robots used the modified design of the basic design plan.

3.5 Integration of embedded robot controller

The individual boards developed in this study integrate and configure the applied system according to the function of applied robots. Here, only the wall climbing robot is described. The controller can be operated by connecting four connectors from the external side. The internal configuration consists of motion, CPU, and I/O boards based on the network hub(including wireless function) and these are connected through a network system. In addition, the motion board and each servo driver are connected by digital I/Os, position commands for the position control, and CAN for the monitoring of the servo state. Also, a commercial power supply of AC 220V is applied to several devices through the power module. Fig. 10 shows the configuration diagram in the robot control box.

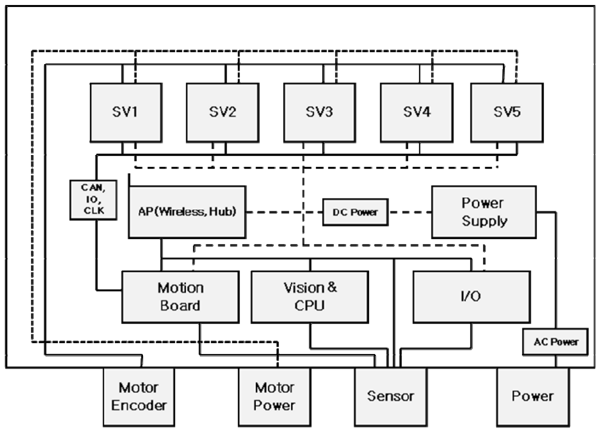

Fig. 10 Internal diagram of the robot controller box

The controller was fabricated for a total of 5-axis and consisted of several devices as mentioned above. The major ideas on the fabrication of this controller were small-scale and stable heat dissipation structure. Regarding the distance between the robot and the robot operator, a display window was installed to easily verify the robot state. Also, the controller was designed to apply an automatic shutdown function for the malfunction in communication through the periodical communication with the host controller as a counter plan for certain malfunctions in robots or communication systems. In conventional technologies, the controller is a separated operation type between the applied robot and their controller and is connected using cables. However, the system applied in this study includes all systems in the applied robot except for the power supply.

In addition, this study configures a proper test standard to verify the reliability of the fabricated controller by considering poor working environments. The test standard includes performance test, durability test, environmental test, and electromagnetic test. Table 3 shows the detailed configuration of this condition. Fig. 11 illustrates the image of an environmental test for the embedded controller.

Table 3. Experimental condition of the robot controller

Test	Test Item	Test Condition
Performance Test	Torque	• Specific torque 1.27Nm, • Maintain for 1 hour (Fail/Pass)
	Speed control	• Specific rpm- 3000rpm, • Equal speed control, 60 trials/time (Fail/Pass)
	Position control	• Within ±0.5°(182) (1131072/360°)
Durability Test	Breakage rate	• 180 trials/time ON/OFF passage
	Long run	• Continued operation for 24 hours
Environmental Test	Low temp. protection	• -55±3℃, 12h
	High temp. protection	• 70℃±3, 12h
	Temp. circulation	• -10℃±3 ~ 40℃±3, 93±3%
Electromagnetic Test	Electrostatic discharge	• Contact discharge 6KV, discharge in the air 8KV
	Impulse Noise	• ±2KV, 50ns
	Surge	• ±2KV, 5KHz

Fig. 11 Experiment on the performance and environmental stability

4. CONCLUSIONS

According to the increase in the applicability of mobile robots in a shipyard to increase their productivity, the requirement of the embedded controller has been increased in the present time. The embedded controller was developed according to the coherent development environment based on the DSP from the early stage of the design. Also, several related control boards were designed and developed for required functions. The developed products were the CPU board including vision functions, motion and driver boards for the servo motor control, and I/O & power board. Furthermore, various communication protocols were implemented by considering the extendibility and flexible applicability in the development stage.

In addition, the functional and environmental test standards were achieved to perform stable operations under poor environments in a shipyard. Also, the successful product fabrication was performed under these conditions.

The embedded controller applied to this mobile robot can be applied to various works in a shipyard, such as practical works, welding, cleaning, painting, and inspection, and that will contribute the increase in productivity and the improvement in working environments.

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