Web Based Monitoring Systems for Multi-Axis Force/Torque Sensors Using Embedded Systems

Hyun-Do Nam*, Hong-Sik Lim and * and Chul-Goo Kang**

* Department of Electrical Engineering, Dankook University, Seoul, Korea
(Tel : +82-2-709-2574; E-mail: hdnam@dku.edu)
**Department of Mechanical Engineering, Konkuk University, Seoul, Korea
(Tel : +82-2-447-2142; E-mail: cgkang@kkucc.konkuk.ac.kr)

Abstract: In this paper, web based monitoring systems are implemented for multi-axis force control systems of an intelligence robot. A brief review about the principle of multi-axis force sensors and a method that can reduce the effect of noise signal to sensor performance is presented. A web based monitoring system is implemented by porting Linux at embedded systems which include Xscale processors. A device driver is developed to receive data from multi-axis force sensors in Linux operation systems. To control this device driver, a socket program for web browser is also developed. The experiments are performed to investigate the effectiveness of proposed methods. The experimental results show that the values of force sensors can be monitored by remote PCs.

Keywords: Web-based monitoring system, Multi-axis force/torque sensors, Embedded systems, Device driver, Linux, Embedded web server, Digital signal processing

1. INTRODUCTION

Today, the number of computer and internet users is rapidly increasing by advancement of information technology. The significant advances in Internet and computer technology have made it possible to develop an Internet-based control and monitoring for industrial systems. The distributed control systems and robotic force control systems in manufacturing automation process using multi-axis force sensor have been upgraded with the web-based technology[1].

Robotic force control in manufacturing automation processes, particularly in contacting processes of end effectors with environment is required for the precise manipulation of robot and the protection of workpiece as well as robot system itself. For this force control purpose, multi-axis force sensor, usually 6 axis force sensor is utilized in order to measure the magnitude and direction of contacting force. The 6-axis force sensor is usually attached to robot wrist, that is, between end effectors and robot arm. In this case, the sensor size and weight are usually restricted to be small to minimize the dynamic effect of the sensor itself on the robot system. In this viewpoint, a strain gage type sensor is one possible choice for this purpose[2-4].

The 6-axis force sensor of the strain gage type usually measures surface strain of elastic members inside the sensor using Wheatstone bridges in the form of analog voltages, and then amplifies the voltage signals and converts them to digital numbers. The linear relationship between external force and measured voltage is satisfied within prescribed force range[5].

Multi-axis force sensors obtain force information by amplifying low-level voltage signals in proportion to external force. In this process, several noise signals are added to useful voltage signals and aggravate S/N ratio of the sensor output. These noise signals are brought about several sources. In order to improve the sensor performance, we need to find a useful way to reduce the noise signals.

In this paper, a web-based remote force management system for mechanical systems under interaction with environment is presented. A web-based real-time program for PCs and embedded systems are developed for data acquisition and processing of multi-axis force/torque sensors. And necessary interfacing devices and embedded hardware are also developed for the proposed system.

2. MULTI-AXIS FORGE/TORQUE SENSORS

When an external force acts on a sensor body, the force-torque sensor detects elastic deformation of the internal structure of the sensor and transforms the deformation to voltage or digital value and calculates the six components (or parts of them) of the acting force. The elastic deformation is usually detected by means of strain gages, optoelectronics, inductive displacement transducers[6], and CCD elements. We consider in this paper force-torque sensors using strain gages and Wheatstone bridges that enables to figure out force and torque by detecting its surface strain of elastic structure[3].

If the elastic deformation of the internal member in the sensor is within elastic limit, the relationship between maximum surface strain of the internal structure and the applied force on the sensor can be written as follows.

$$Cf = \varepsilon \tag{1}$$

where $\mathbf{f}$ is a measured $1 \times n$ force vector whose components are consisted of force components and/or moment components, ε is a measured $1 \times m$ strain vector whose components are consisted of m strain measurements of m points on the internal structure, $\mathbf{C}$ is a measured $m \ x \ n$ compliance matrix or calibration matrix. We assume that $m \geq$ n and rank ($\mathbf{C}$) = n) without losing generality. The condition $m \geq$ n implies that the number of strain measurement points is equal to or greater than the number of force components we want to seek. Generally n is equal to or less than 6.

From above equation, the following solution or approximate solution is obtained.

$$\varepsilon \ = \mathbf{C}^{+} \mathbf{f} \tag{2}$$

where $\mathbf{C}^{+} = (\mathbf{C}^{T}\mathbf{C})^{-1}\mathbf{C}^{T}$, and $\mathbf{C}^{+}$ is called left pseudo-inverse. The left pseudo-inverse is a special case of Moore-Penrose inverse that can be defined in a matrix with non-full rank.

Moore-Penrose inverse is derived from the singular value decomposition. Fig. 1 shows a schematic functional diagram of force sensing procedure.

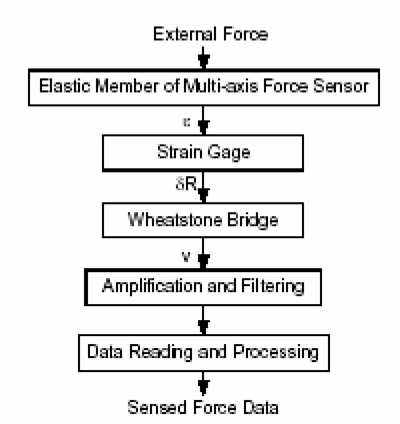

Fig. 1 Force-sensing procedure

3. DATA ACQUISITION SYSTEMS

Developments of computer technologies and internet technologies made it possible to monitor and control via internet in modern industrial fields. Automation manufacturing processes using multiple force sensors in distributed control systems and robot force control systems improved using web-based monitoring and control systems.

The 6-axis force sensor having been developed in our laboratory includes 6 Wheatstone bridges and amplifying circuit inside the sensor body. Remaining electronic components were installed on the signal processing board in a web-based monitoring system. In this case, the sensor outputs were contaminated lots of noise signals due to electromagnetic waves and AC electric source (EMI). In order to improve the sensor output signals, the low pass filter is used and we convert the amplified voltage signals to digital values and then read them in the embedded system. Fig. 2 shows the schematics of the web-based monitoring and control system.

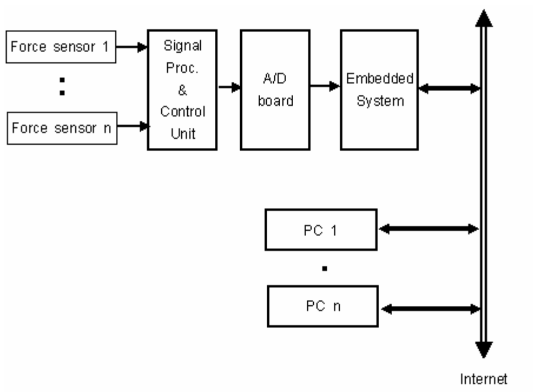

Fig. 2 Schematics diagram of the web-based monitoring and control system

3.1 Anti-aliasing filter

The elastic deformation detected by strain gages is converted to the variation of electric resistance, and this resistance variation is transformed to small voltage changes through Wheatstone bridge. After amplify this small voltage change using operating amplifier circuit, pass a low pass filter to remove noise that is included in signal.

In this research, Sallen-Key Topology's second order Butterworth low pass filter, as shown in fig. 3, is used to maintain the flatness property in pass-band frequency. Considering sampling time and bandwidth of usual machine, the cutoff frequency of the low pass filter is chosen by 102Hz.

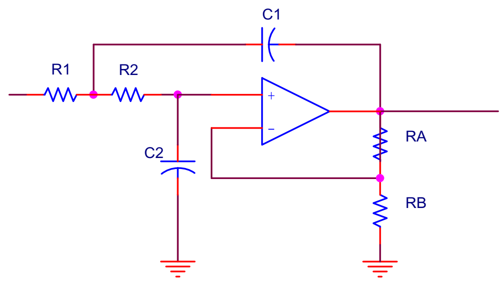

Fig. 3 Circuit of second order Butterworth low pass filter

3.2 A/D converter board

A MAXIM MX7828LN which has 8 bit 8 channel analog inputs and 2.5μsec converting time is used for A/D converter that converts analog data of multi-axis force sensors to digital signal. A circuit diagram of developed A/D board is shown in fig. 4 and a whole picture including A/D board and an embedded system is shown in fig. 5.

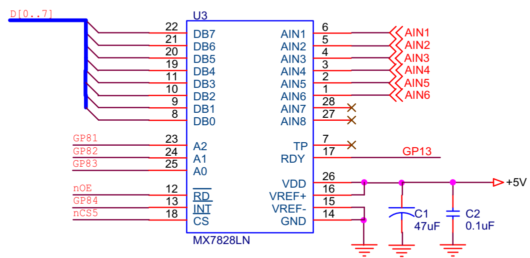

Fig. 4 Circuit diagram of A/D board

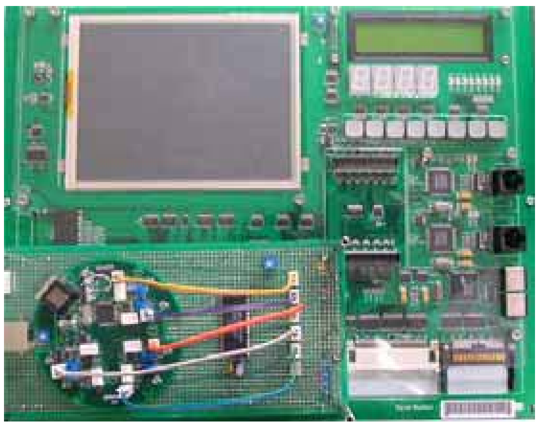

Fig. 5 Picture of a whole system

4. WEB BASED MONITORING SYSTEMS

Embedded systems are becoming increasingly complex. Not only is there increased functionality, but the system architecture is also becoming more complex. Specifically, (message passing) systems have become an attractive choice because they offer good price performance tradeoffs. Web based monitoring system for multi-axis force/torque sensors is implemented using embedded systems which have ARM core CPU.

4.1 Embedded web server design

We have designed an embedded web server(EWS) that consists of five parts: an HTTP engine, a virtual file system, an application interface module (device driver) and a common gate interface(CGI).
The most important part of the EWS is an HTTP engine, which serves a client's request. The minimum requirement for an HTTP engine is that it must be compliant with HTTP specifications for communicating commercial Web browsers. A Boa web server is used to support HTML protocol and CGI. Goahead web server is used in this research, fig. 6 shows comfiguration of an embedded web server.

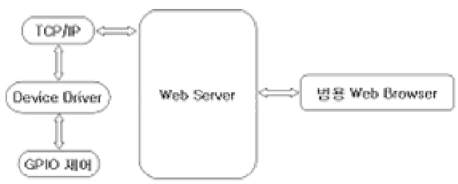

Fig. 6 Configuration of embedded web server

The virtual file system (VFS) provides the EWS with virtual file services, which are file_open for opening the file, file_read for reading the file, and file_close for closing the file after reading. The file system such as RAM disk, Jffs, Jffs2, Cramfs, Ramfs, can be used, which depend on target board specifications. RAM disk file systems with flash file systems (Jffs, Jffs2) are used in this research.

4.2 Device driver development

The OS provides a standard interface between programs (user or system) and devices. A device driver is necessary to control hardware peripheral devices in LINUX operating system as shown in fig. 7. Other peripheral devices are called devices except computer system with hard-disk, floppy disk, printer, scanner and computer systems can access devices through files in LINUX. A device driver, which is a collection of subroutines and data, interface to exchange data between devices and systems[7].

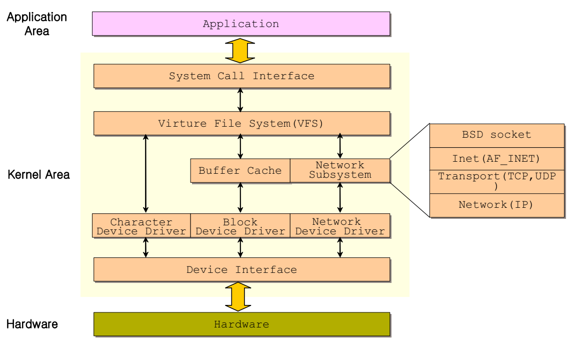

Fig. 7 Structure of Linux system

Device drivers are the processes responsible for each device type. A driver encapsulates device-specific knowledge, e.g., for device initiation and control, interrupt handling, and errors. There are three types of device drivers; a character device driver, block device driver, and a network interface driver[8]. A character device driver is developed to control force/torque sensors using web server in this research. A character device driver is a device that has order of data, and supplies raw data of devices to user without buffer cash[9]. Fig. 8 shows the structure of a character device driver and fig. 9 shows the configuration of the developed device driver.

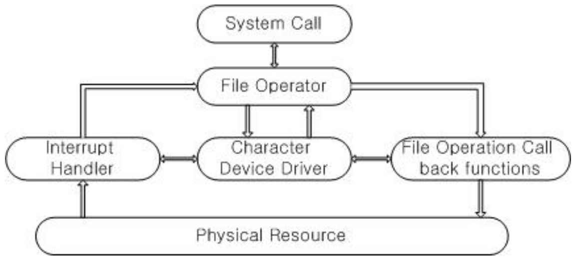

Fig. 8 Structure of a character device driver

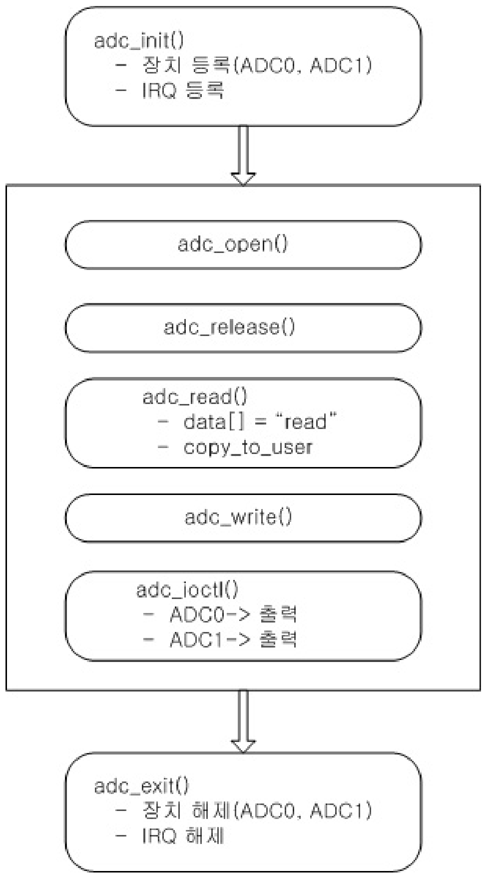

Fig. 9 Configuration of the developed device driver

4.3 CGI program development

A web server application receives HTTP request messages from a web server. Web server applications consist of either a Common Gateway Interface (CGI) or use a web server Application Programming Interfaces (APIs) which is usually a Dynamic Link Library (DLL)[10]. The CGI permitted the first web application programming between the user application of a web browser and applications located on the web server. CGI program is developed using C. Fig. 10 shows the flow chart of CGI program.

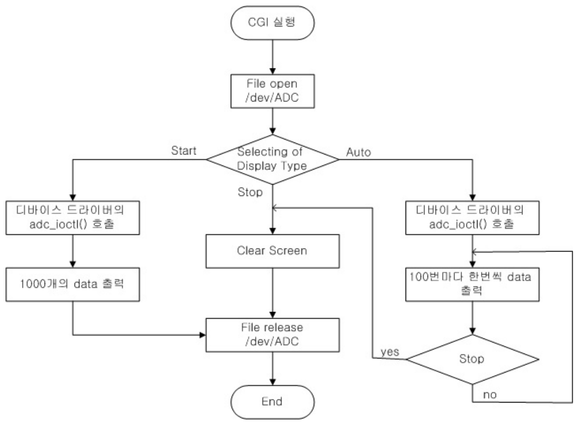

Fig. 10 Flow chart of CGI program

5. EXPEREIMENTS

Experiments of a web based monitoring system with force/torque sensors, as shown in fig. 11, have been performed to investigate the effectiveness of the proposed system.

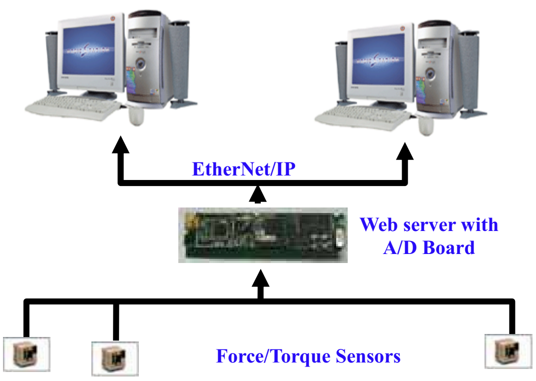

Fig. 11 Configuration of experiment system

If the PCs which are connected to internet lines call the embedded web server, web servers detect the force/torque signals from sensors via A/D board and send the signals to PCs via Ethernet. The force/torque signals can be monitored by using web browser that is executing in PCs as shown in fig. 12.

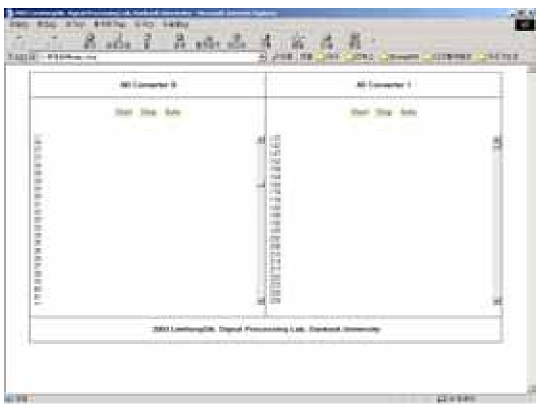

Fig. 12 PC display of web browser

6. CONCLUSIONS

In this paper, web-based monitoring systems are implemented using embedded Linux. The measuring instrument is controlled via HTTP protocol and web browser program. HTTP protocol is ported into Linux. A micro web server program and measuring instrument control programs are installed on-board memory using CGI. Experimental result of the proposed web based monitoring systems for force/torque sensors shows that the force/torque signals can be remotely monitored via internet using web browsers on PCs.

ACKNOWLEDGMENTS

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