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Real-time data acquisition system and HMI for MES †

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Abstract

MES (Manufacturing Execution System) is a powerful production management tool supporting production optimization from the process initiation to the final shipment. It not only transmits the production information to production planning systems like ERP (Enterprise Resource Planning) and SCM (Supply Chain Management) in real-time, but also orders the planned production data to the production site. It is a production management system which plans and executes based on the production data in the field, thus it must be operated with a data acquisition system which gathers the accurate field data in real-time. This study deployed the data acquisition system and HMI (Human Machine Interface) system to collect real-time equipment data through the interface with the equipment to develop MES, and the developed system was applied to the machine tool for verification of its effectiveness. The test indicated that the equipment operating time and other operating data of the equipment could be processed without the interference of the workers. The developed data acquisition system and HMI can be applied to other equipment by using different sensors.

Keywords: Data acquisition system; Equipment interface; HMI (Human Machine Interface); MES (Manufacturing Execution System); Real-time; Sensor-based I/O interface

1. Introduction

MES (Manufacturing Execution System) is a system to optimize production from the initial product order to its shipment, and includes overall activities for production execution such as scheduling, work order, quality management and work performance needed by the job on the shop floor. It has the most fundamental and important role as a hub performing functions such as transferring the latest production data to a higher level production planning system like ERP (Enterprise Resource Planning), SCM (Supply Chain Management) and CRM (Customer Relationship Management) as well as sending the production data planned in the higher level to the production management level.

Without MES or POP (Point of Product), the enterprises depend on manual work from production planning to delivering it to the worker, and cannot check the operating condition of the equipment in real-time. When the production expands and process becomes more complex, the data such as actual production, equipment malfunction and quality are determined by worker discretion, which makes it difficult to transparently manage the plant, and manual logging results in inaccurate productivity analysis.

As such, more and more enterprises are introducing MES. However, unlike the manufacturing solution systems like ERP, SCM and CRM that contain many available solutions, it is difficult to select an appropriate MES because they have different production methods and are very industry specific. Furthermore, because of the characteristics of MES, high costs and efforts required to design, implement and utilize the system make it difficult for small and medium size companies to introduce it. Even after the introduction, it is not widely applied in reality because of inadequate follow-up support, lack of flexibility because of fixed functionality of the off-the-shelf products, and lack of modularized systems that can be applied according to the management capability level of the enterprise.

In the manufacturing production system, the processes differ according to the characteristics of the products, thus the data generated by each process are also diverse. To deploy the MES befitting the different processes and specialized shop floor, it is most important to efficiently collect the production data such as the production volume, defect data, equipment operating data and equipment status data generated on the shop floor with consideration given to various shop floors and equipment.

This paper introduces the shop floor data acquisition system, which specializes the data acquisition function of MES to efficiently collect and manage the data generated by the production process and shop floor.

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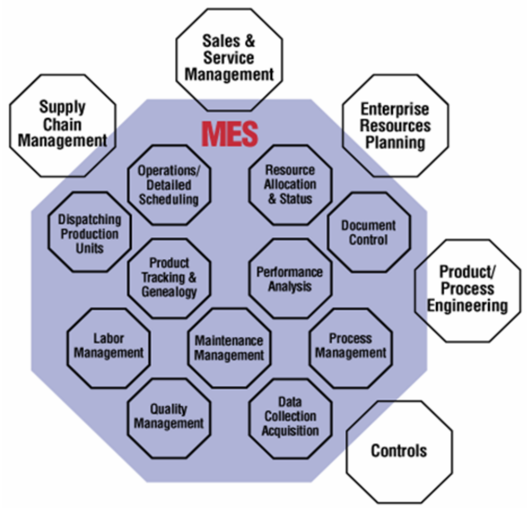

Fig. 1. ISA-95 Enterprise-control integration standard.

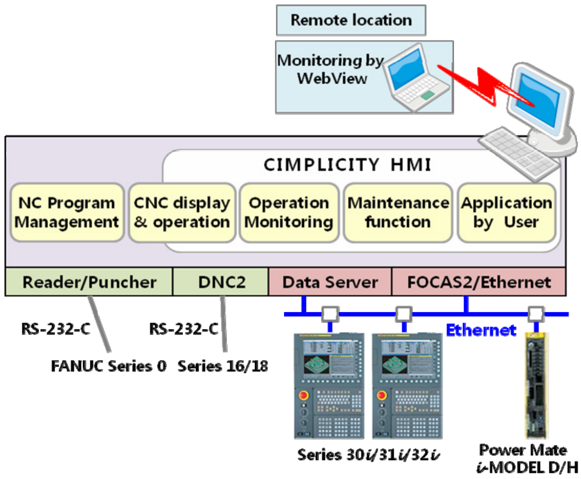

Fig. 2. Monitoring concept of FANUC Cimplicity ***i*** –Cell (reference site - http://www.fkc.co.kr).

2. MES & equipment monitoring

2.1 MES

MESA (Manufacturing Enterprise Solutions Association International) defines MES as follows: MES is systems that deliver information enabling the optimization of production activities from order launch to finished goods. Using current and accurate real-time data, MES guides, responds to, and reports on plant activities as they accrue. The resulting rapid response to changing conditions, coupled with a focus on reducing non-value added activities, drives effective plant operation and processes.

The model proposed by MESA has well defined functions and is widely applied commercially. Of the various models presented by MES, ANSI/ISA-95 (2000), the enterprise-control integration model proposed by MESA and ISA, is most widely referred. The ISA-95 model became the international standard as IEC/ISO 62264 in 2002.

Fig. 1 shows 11 MES functions proposed by MESA [1]. It considers MES function as the integration of all data such as the process monitoring and control data, equipment control and monitoring data, quality data, tracking and control data, actual output data, material input data, labor management data, etc. generated on the shop floor.

MES is a dynamic execution oriented system and performs the function of ordering and controlling the various events generated on the shop floor using accurate field data. The functions provided by MES manage the production activities from the time of production order to the shipment of the finished goods. MES also provides important production activity information through the bidirectional information interchange with the enterprise and supply chain domains. As such, it has become the key system that directly affects the product quality improvement and productivity improvement.

Although MES began from MRP (Manufacturing Requirement Planning), SFC (Shop Floor Control), and PM&C (Production Monitoring & Control) in the 1980's, it had advanced to integrate the shop floor with ERP in the 1990's and to the e-manufacturing model in the concept of BPM (Business Process Management) with the widely increasing use of the Internet in the 2000's.

RTE (Real-Time Enterprise) has gained prominence in the manufacturing environment from product development to production [2, 3, 4]. With such change in the environment to embody RTE, reduction of the product development gap and production lead-time, quick and accurate response to orders, process tracking and data sharing with customers and partners have become more important.

The realization of RTE requires the vertical integration of ERP systems with the manufacturing execution [3]. Available EAI (Enterprise Application Integration) systems can be used to horizontally integrate existing business applications [5]. Nevertheless, EAI lacks in incorporating manufacturing resources (e.g., CNC machines) in vertical direction. Hence to achieve vertical integration of an enterprise, MES were introduced [6]. In the future, MES is expected to advance to the collaborative manufacturing system, which is defined as CPM (Collaborative Production Management) by ISA-95 and CMM (Collaborative Manufacturing Management) by ARC Advisory Group [7]. As such, flexible collaboration of MES with enterprise systems such as ERP, SCM, CRM, and PLM (Product Lifecycle Management) is becoming more important.

2.2 Trend of equipment monitoring

Manufacturers all have HMI (Human machine Interface) solution, the general purpose monitoring system used to check the objective shop floor data anywhere and anytime and to take immediate proper measures. Using an internal API such as e-Tower (by Mazak) or Cimplicity ***i***-cell (by Fanuc) as shown in Fig. 2 is expensive and unsuitable for general purposes, as they only work with particular systems from the same manufacturer. However, such systems force task repetitiveness, thus lowering the development productivity and make operation and maintenance difficult. That is because the system customized for the manufacturer must be developed, and users must learn the operation each time when it is applied on the site.

The leading machine tool makers in Japan and Europe introduced exclusive CNC monitoring systems like Mazak-Cyber Production Center, Moriseki-MORI Series, and Siemens-MCIS. However, such systems still lack generality as they are oriented toward the maker's own products and highly prices and not sufficiently flexible [8]. Open CNC systems applying the Open API like Fanuc's FOCAS1/2 (Fanuc Open CNC API System 1 or 2) or OPC (OLE for Process Control) interface, which has become the industrial standard, can solve the above problems, but they are optimized for the distributed environment, which makes it difficult to provide the after sales service remotely.

SYNTEC of Taiwan has introduced PC-based CNC controllers to extract the equipment status data through PC-NC. The systems use the open CNC controller technology based on remote CNC and PC which transfer the equipment statuses of multiple units to the status data acquisition system through wired and wireless communication to enable remote monitoring over Internet. Mitsubishi of Japan developed the NC monitoring system and PC based CNC system to monitor and control its machine tools over Ethernet with an HMI system. The system enables a user-defined screen and a CNC controller interfaced to DNC. Fanuc sells HMI which monitors the pressure and temperature applied to the equipment using the pressure sensor and CNC API.

The latest trend is automated machine tool controllers like CNC becoming the open system, and many tools to monitor the equipment remotely are being developed. Production equipment like lathe turning machines, milling machines and grinders are mostly controlled by CNC. Because these machines are typically operated standalone, they have a custom manufactured or limited functional CNC controller. To monitor the equipment status, PC-NC with diverse functionality, API to interface with sensor data, and user defined HMI architecture will be needed. Besides such automated systems, general industrial machines like the press machine, grinder machine and milling machine provide the monitoring systems with the ability to check the individual work volume, but the methodology for equipment monitoring does not yet seem to have proliferated widely.

3. Equipment data acquisition through equipment interface

In enterprise production without MES, there is the problem of data reliability as the equipment status data depends on worker discretion from production planning to work order to the worker, and errors can occur in manually entered records. Furthermore, in production that produces many different products in small volumes or a production line that has a significant capacity and complex process, the site status may not be checked in real-time, making it impossible to immediately respond to the business needs. That will generate many problems such as sales loss, failure to deliver on time, and reduced factory operation, causing deterioration in competitiveness. The survey of typical shop floors indicates that only 23% of all factory machines enable data acquisition through direct interface. As such, the means to collect data specific to the process characteristics of each industrial site, and technology to support the equipment to enable such data acquisition are needed. This study designed a real-time data acquisition system by applying the enterprise domain hierarchy proposed by ISA-95 as shown in Fig. 3. MES constitutes level 0 to level 3 while the equipment interface constitutes level 0 to level 2. The machine or equipment in level 0 collects the shop floor data through the RFID and direct interface in level 1. The data collected through the sensor-based interface are provided by HMI through the data acquisition system of level 2 for easy monitoring.

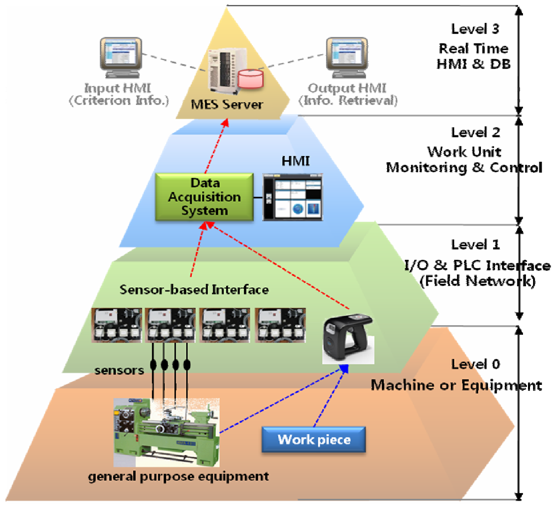

Fig. 3. ISA-95 Enterprise domain hierarchy and proposed data acquisition system architecture.

The data are also sent to the MES server in level 3 for other applications. The proposed method conforms to the conventional MES definition and functionality, and the advanced primary data acquisition method will be able to support the real-time data acquisition and conformity to the process characteristics differently according to the manufacturing industry.

Fig. 4 shows the architecture of the proposed data acquisition system which mainly consists of the interface module, data collection module and monitor module. In the past, timeliness and the transparency of the data were poor because data other than the equipment data extracted from the equipment were manually recorded on the paper.

The system features the RFID based auto-detect function and sensor-based interface function to directly collect the shop floor data. The equipment status data obtained by the interface module are sent to the data collection module. The data collec-

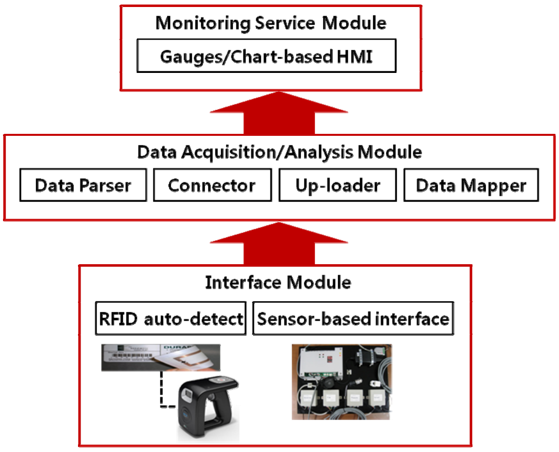

Fig. 4. Data acquisition system architecture.

tion module processes and analyzes the collected production data and sends them to MES so they can be monitored by HMI.

3.1 Sensor-based interface

The sensor-based interface method is used for general purpose equipment without a controller such as the CNC. It can collect the equipment status data by measuring the temperature, voltage, vibration, heat and other factors generated when the equipment is in use. These sensors are attached to the equipment and collect the equipment status output signal in real time. To check the equipment data collected by the sensor-based interface, a test to measure the temperature and voltage of the equipment was performed. To acquire the equipment temperature and voltage data, an I/O interface unit was designed. It consists of a unit for collecting the I/O interface production data, a communication unit for RS232C or other protocols, and a sensor detection unit.

The input unit consists of A/C, D/C, RS232C, RS485 and other elements. The output unit can measure the voltage. The input power source is DC7.5V-DC30V.

The RS485 communication is connected to the mains while RS232C communication can be connected to the PC or other devices. 0-36V was input as the measured power for the test. Sensors to measure the temperature and voltage and externally expandable sensors were additionally designed. The externally expandable sensors can have up to 256 additional sensors to increase the flexibility of data collection. The status data collected by the I/O interface unit are sent to the Data Acquisition/Analysis Module using RS485 serial communication. This method uses the 1:1 mapped I/O interface unit and equipment. Up to four devices can be connected to each shop floor monitoring system.

This paper proposes a sensor-based interface technique which is applicable universally using any type of sensor under any situation without changing the system, not limited to acquiring status information using specific sensors. The sensor-based interface is implemented using a sensor-based I/O board which provides the terminals for the temperature and voltage sensors which can measure 5 temperature points and 2 voltage points and external extension sensors. The sensor-based board consists of the sensor detector for measuring the temperature and voltage sensors, communication component for supporting communication such as RS232/RS485, and I/O control part. The input power supply of the board ranges 7.5VDC~30VDC and the RS232 communication can be connected with a PC or other external devices. The board was designed to support the temperature and voltage sensors whose measurement range from -19.9 degrees Celsius to 99 degrees Celsius and from 0V to 36V, respectively.

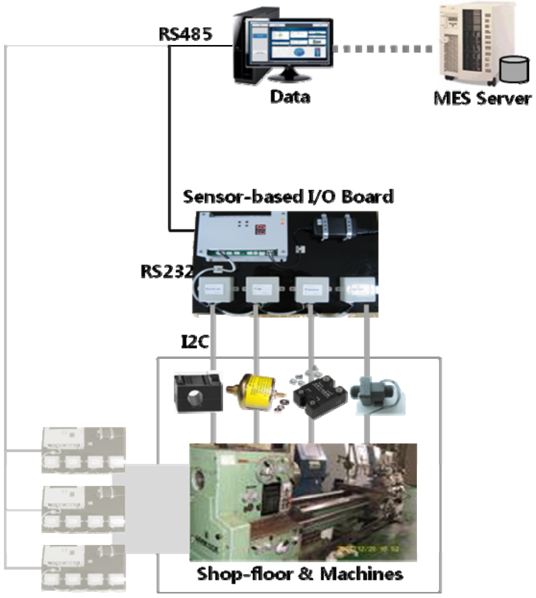

Fig. 5. Configure of shop floor monitoring system using sensor-based interface.

The extension sensor terminal block is designed to accommodate up to 256 sensors of various kinds to achieve high flexibility in acquiring status information.

In order for real-time based monitoring of the status information of machines using the sensor-based interface, the interface environment can be configured with one shop floor monitoring system client built-in with a data collection module and up to four sensor-based I/O boards, as illustrated in Fig. 5. As necessary, the sensor-based I/O board can be connected with extension sensors. In this study, the maximum number of the extension sensors is limited to four to secure system stability. The data from up to 11 sensors can be collected with the seven basic temperature and voltage sensors and the four extension sensors. Therefore, the sensor-based interface environment configurable with one shop floor monitoring system client can monitor up to 44 data sensors. The extension sensors are connected to the sensor-based I/O board using external sensor connectors and transmit data using the I2C (Inter-Integrated Circuit) protocol which is a 2-line serial communication speci-

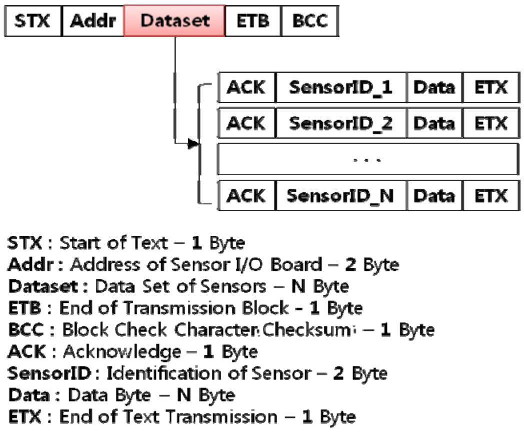

Fig. 6. ID Auto-detect using RFID.

fication between the chip and board. I2C is a serial computer bus used to connect low-speed peripheral devices with a mother board or embedded systems.

The sensor data of the machines collected with the sensors is transmitted to the shop floor monitoring system client via serial communication using the communication protocol shown in Fig. 6. The definition of the communication protocol is based on a character-oriented protocol which uses special characters (synchronous characters, link control characters) at the beginning and end of messages to synchronize the transmitter and receiver.

The frame structure of the communication protocol between the shop floor monitoring system and I/O board consists of transmission starting byte (STX), sensor I/O board identification byte (Addr), sensor dataset byte (Dataset), block transmission ending byte (ETB), and checksum byte (BCC). Of the frame structure, the sensor dataset byte has its own specific frame structure to support the transmission of the data of each sensor. The frame consists of an acknowledgement response byte (ACK) generated at the receiver for the information received, a sensor identification byte (SensorID), sensor measurement data byte (Data), and an end of text byte (ETX) notifying the data loading of all the sensors has been completed, and all of these can be repeated for N times according to the number N of sensors.

The data byte is the combination of the status information of the machines measured with the sensor and specific delimiter. When no sensor measurement data is available, FAIL which represents the communication failure while the sensor is operating or N/A which means the sensor is not in connection can be selected and sent. Due to this protocol definition, it is possible to identify the sensor I/O board which receives the signal, and it is not necessary to repeat the communication having the format of [request-response] to receive the sensing value of the sensor of a specific equipment, but executing the ALL function which enables receiving the measurement values of all the sensors by requesting [STX|Addr(N)|ENQ], to enhance the reliability of real-time based measurement.

This communication structure which is a kind of 'ALL'

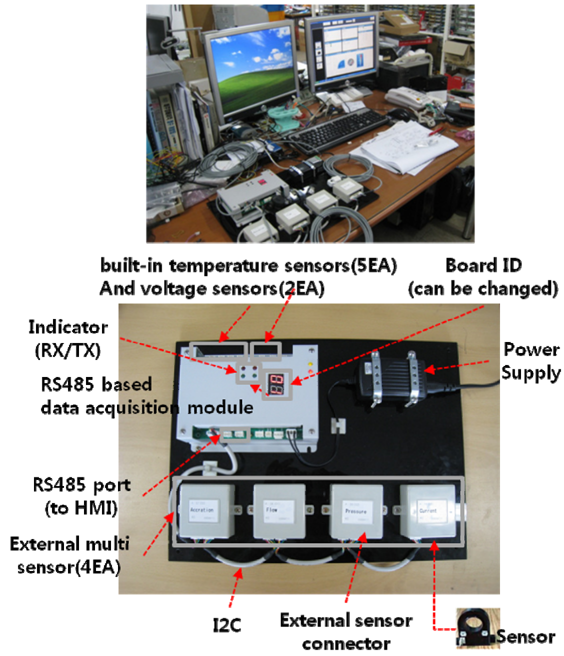

Fig. 7. Configuration of sensor-based interface.

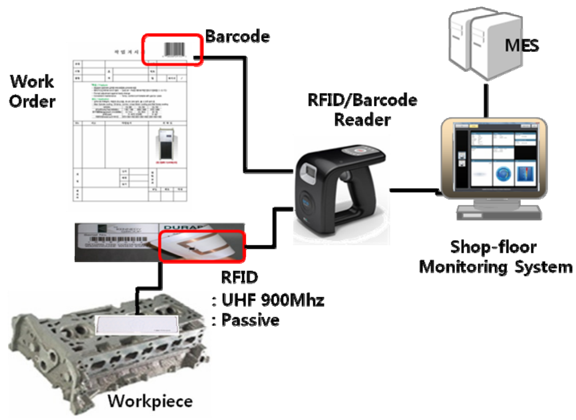

Fig. 8. ID Auto-detect using RFID.

function can eliminate the unnecessary operation of requesting the data already received, in case of communication error or data loss. Fig. 7 shows the monitoring of the temperature data collected by the sensor-based I/O interface unit.

To prevent distrust and error from manual data entry, the RFID system featuring work-piece, worker ID recognition and a paper-less system to minimize manual entry, ID auto/error check, tracking system for the data movement [9, 10], and automatic acquisition/management of timestamp was applied. It used 900MHz UHF spectrum to appropriate for the shop floor and a passive chip-less RFID tag with an effective recognition distance of 2.5 m. To minimize interference, metals were shielded with the masking reagent. There are studies of RFID which can recognize accurately regardless of the position of the work-piece, and they are many cases of its application on the shop floor. Fig. 8 shows the flow of the data collec-

Data	Description	Example
Primary Shop floor Data	Equipment interface or manual entry data	Voltage, RPM, On/Off, temperature, humidity, alarm, manual entry, CNC door open/close, CW/CCW of CNC spindle, etc.
		1st Processing
Secondary Shop floor Data	Data generated after 1st processing	Operating time, idle time, malfunction time, equipment history, good product, defects, quantity, standby before the process, preparation time, standby after the process, etc.
		Mapping
Reference Data	System reference data	Worker data, product data, organization data, process data, equipment data, product order data, work order data, etc.
		2nd Processing
Tertiary Shop floor Data	Data generated after mapping of the primary and secondary data with the system reference data	Daily production by equipment, total daily production, average product production time by equipment, work output, work start time and end time, etc.

Fig. 9. Processing of collected primary shop floor data.

tion using an RFID auto-detect work order form or work-piece without manual entry.

3.2 Data acquisition module and HMI

The shop floor data collected by the sensor-based interface in real-time were transferred through the predefined protocol. The data parser of the data acquisition system interpreted the data frame of the raw data using the regular expression and decomposed the raw data. Since the data frames transferred by the sensor-based interface were different, it defined the regular expression specifically to each interface. This study used POSIX (Portable Operating System Interface [for Unix]), which was the IEEE standard.

The primary data such as the voltage, current, and RPM generated by the data parser were processed to calculate the secondary data such as the operating time, idle time, malfunction time and defect with reference to each data criteria.

The secondary shop floor data were mapped with the reference data with the data mapper of the data acquisition system to generate the tertiary data, like daily production volume by the equipment, average production time, and work performance. Fig. 9 shows the secondary and tertiary data generated by processing and mapping of the shop floor data. The database was developed to store the collected data. It consists of the system reference data and shop floor data. It also has a connector to manage the collected data and an up-loader to transfer the data to the MES server. The processed and calculated shop floor data are in text format and thus have the problem of poor legibility to make it difficult for users to find the needed information.

Since the data collected in real-time are accumulated as time passes, legibility becomes even poorer, and it makes it almost impossible to effectively process and utilize them. As such, the collected shop floor data were presented in gauge or

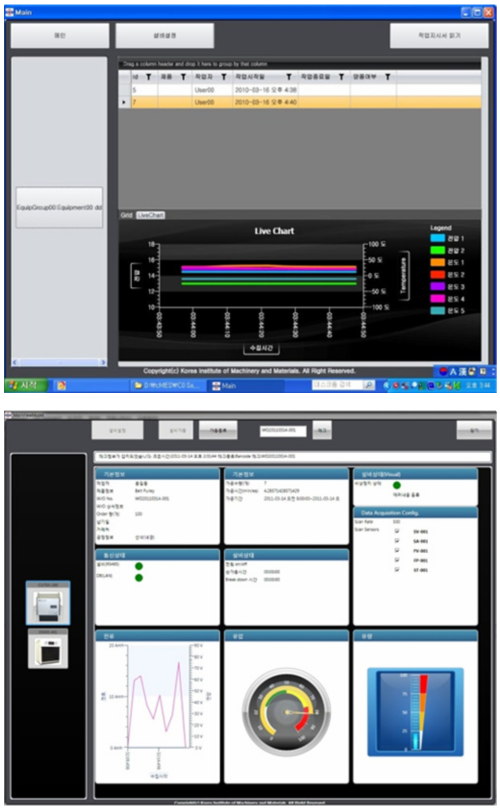

Fig. 10. Real-time monitoring using HMI.

chart based HMI as shown in Fig. 10. Different presentations were used according to the type of collected equipment data. The temperature values of different parts of the equipment were presented in a graph while the current measurements were presented in a trend line, and oil pressure and oil flow rate were presented in a gauge form so that users could monitor if they were in the safe range. Since the system is operated in a general purpose personal computer, it solves the cost and performance problem and thus the program can be made lightweight to ensure the stability of the communication and system.

4. Application

To verify the effectiveness of the developed sensor-based interface based data acquisition system and HMI, they were applied to two general purpose machine tools and one CNC based composite tool for testing. The current sensor, acceleration sensor and flow rate sensor were installed in the general purpose lathe (HL-460 from company H), which was mostly used for lathe turning, to collect the lathe operation on/off information and status in real-time as shown in Fig. 12. The current was higher when the lathe was operating than when it was idle.

The vibration detected by the acceleration sensor also increased. They are shown in Fig. 11. The HMI for lathe turning machine displays the simple data about the parts currently in

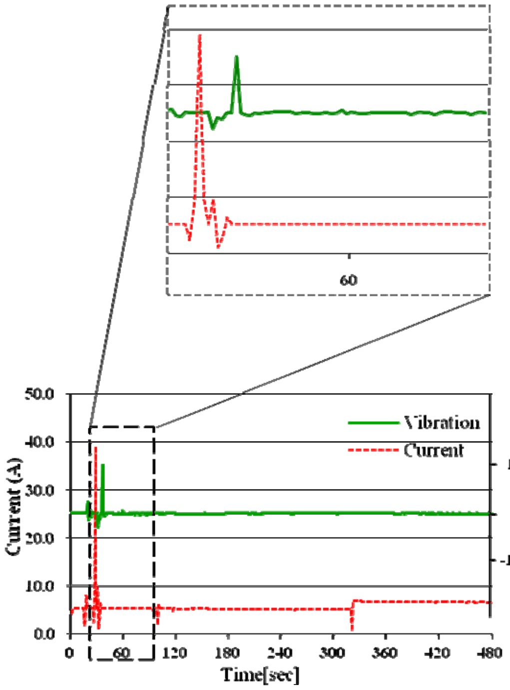

Fig. 11. Example of current and vibration by a lathe in operation.

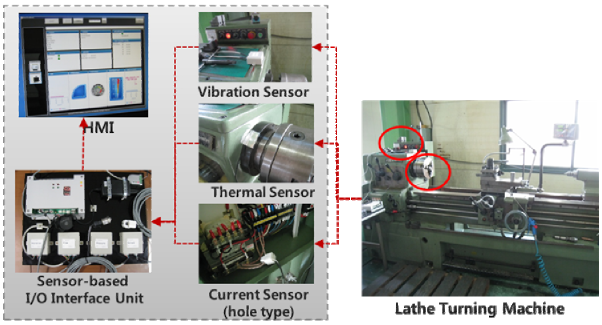

Fig. 12. Example of application on lathe turning machine.

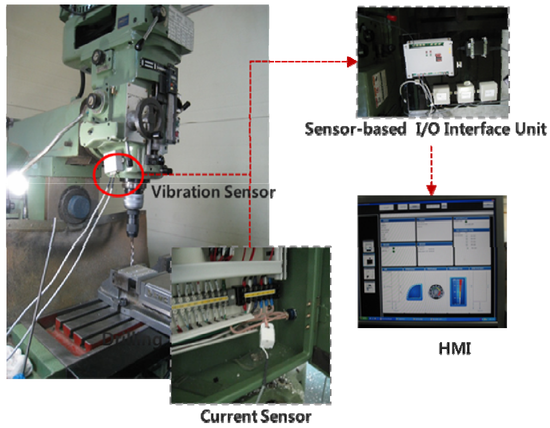

Fig. 13. Example of application on vertical general purpose M/C.

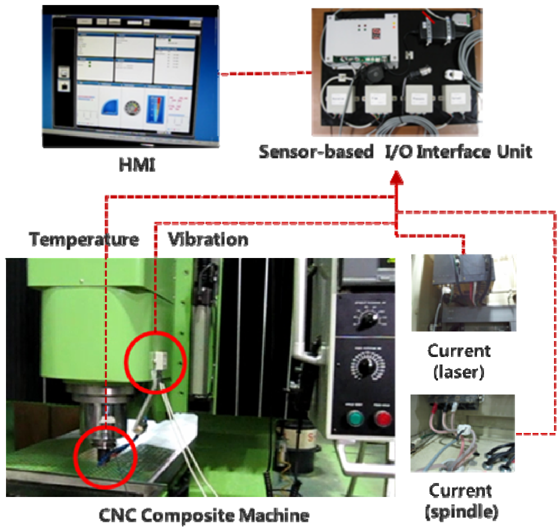

Fig. 14. Example of application on composite machine tool.

operation and signals of the sensors installed in the lathe. The system also automatically calculates the lathe operating rate as well as total operating time and net operating time from the change of the current, to provide the equipment history, efficiency and other reference data. The current and vibration sensors were also installed in a vertical M/C (HMTH1300 from company H), which is typically used for drilling, to test it in the same way as the lathe machine as shown in Fig. 13. In all general purpose and CNC machine tools, about 5A current generally flows when the power is turned on and higher current flows when the motor begins to move. Therefore, the equipment operating rate is calculated by assuming that the equipment is in operation if the current is 5A or higher, idle if it is 1~5A, and stopped if it is 0A.

Lastly, the system was deployed to collect the status data of the composite machine tool, which combines the CNC based vertical machining center with laser welding functions. As shown in Fig. 13, the sensor-based interface unit has two current sensors to measure the current of the spindle and the laser welding machine at the same time. The work operation can be determined by monitoring the current and vibration of the equipment as well as the processed current value.

5. Conclusion

This paper describes deployment of the data acquisition system to collect the accurate shop floor data in real-time and its HMI system to specialize the data collection function of MES, which plans and executes based on the shop floor data. Through the sensor-based direct interface with the equipment, the shop floor data were collected in real-time even in general purpose machines that do not have controllers like CNC. The data collected through the sensor-based interface were processed to calculate the secondary and tertiary data. The generated data could be monitored with the HMI system. To verify the effectiveness of the developed system, it was applied to the machine tools. The test confirmed that the data generated on the shop floor or equipment could be processed without the interference of the workers. Furthermore, the data collected by the data acquisition system in real-time are the reference data to improve productivity by efficiently distributing the production resources and predicting the production capacity. In addition, collecting the equipment/process data in the shop floor level can help better manage the equipment and deploy more powerful MES. That will eventually contribute to laying out the ground for RTE, which emphasizes collaboration and real-time execution.

References

[1] MES Explained: A High Level Vision, MESA, 1997.

[2] A. Drobik, M. Raskino, D. Flint, T. Austin, N. MacDonald and K. McGee, *The Gartner definition of real-time enterprise*, Tech Report, Gartner Inc. (2002) 1-3.

[3] S. Karnouskos, D. Guinard, D. Savio, P. Spiess, O. Baecker, V. Trifa and L. de Souza, Towards the real-time enterprise: service-based integration of heterogeneous SOA-ready industrial devices with enterprise applications, *Proc. of the 13th IFAC Symposium on Information Control Problems in Manufacturing (INCOM '09)*, (2009) 2127-2132.

[4] J. Lee and K. Siau, S. Hong, Enterprise integration with ERP and EAI, *Communications of the ACM,* 46 (2) (2003) 54-60.

[5] D. S. Linthicum, *Enterprise application integration*, Addison-Wesley Longman, Amsterdam (2000) 1-22.

[6] J. Kletti (Ed.), Manufacturing Execution System–MES, Springer, Berlin (2007).

[7] MESA, ISA SP88, ISA-95, USA.

[8] D. J. Sun, *Machine tools by using real-time network management system*, Mitsubishi Heavy Industries technical review, 39 (4) (2002).

[9] Y. Lei, H and C. B. Chan, RFID-based logistics control system for Business-to-business E-commerce, *Proceedings of the International Conference on Mobile Business*, IEEE (2005).

[10] R. Bert, Willoughby, Bar coding gaining wider acceptance in manufacturing and distribution Functions, *Industrial Engineering* (1983).

[11] S. J. Nam, S. W. Lee, J. K. Lee and J. K. Park, Acquisition of data of equipments on shop floor using interface between various equipments, *Transactions of the Korean Society of Mechanical Engineers- A*, 35 (2) (2011) 149-156.

[12] J. K. Lee, S. W. Lee, S. J. Nam and J. K. Park, Design of information acquisition system for equipments on shop floor, *Transactions of the Korean Society of Mechanical Engineers- A*, 35 (1) (2011) 39-45.

[13] S. W. Lee, J. K. Lee, S. J. Nam and J. K. Park, Monitoring system of equipment in shop floor for embodying MES, *International conference on Computers & Industrial Engineering 40th (CIE40)*, (2010) 1-6.

[14] L. Wang, P. Orban, A. Cunningham and S. Lang, Remote real-time CNC machining for web-based manufacturing, *Robotics and Computer-Integrated Manufacturing*, 20 (6) (2004) 563-571.

[15] J. Mahfoud, J. Der. Hagopian, N. Lévecque and V. Steffen Jr., Experimental model to control and monitor rotating machines, Mechanism and Machine Theory, 44 (4) (2009) 761-771.

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