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Information Visualization of Networked Assembly Robots

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***Abstract*—The purpose of this study is to visualize the process information for the networked assembly robots through the Internet. In the past, the process information specific to the robots has not been readily available, hence any corrective actions or preventive maintenance have to be performed based on the inaccurate estimation. To counter such problems, this study utilizes the advanced ICT technologies in order to extract the critical data from the networked assembly robots. The data are then transformed and provided in the form of visualized information to the operator. In other words, the operator can now properly observe and understand the past and current robotic working data that span the entire process steps. More accurate decision can be made through the availability of such data, which will lead to more efficient robotic operations.**

***Index Terms*—process information, real-time monitoring, data visualization, networked assembly robot, enhanced operations**

I. Introduction

The future companies will operate their production facilities in various locations, while taking a strategy for enhanced efficiency. In this distributed productions systems, numerous process information will be generated in real-time and proper means of processing monitoring becomes very important. This includes the visualization of a large amount of information and provision of such information to the operator in order to make timely and correct decisions as to the management of distributed production facilities. In the past, the availability of process information was highly limited, due to the lack of technologies and the high cost of obtaining critical information [1]. Without the accurate information regarding the process operations and the status of equipment, any decisions made to the corrective actions or preventive maintenance can be imprecise [2]. Imprecise decisions evidently leads to an immature line stoppage for the scheduled maintenance, which will induce unnecessary spending as well as the waste of resources. Therefore, a lack of accurate process information becomes the major hindrance to the future production systems [3]. In accordance with the theory of quality engineering, product quality is not only affected by manufacturing process which is sub-step production system but also high-level process such as production management, scheduling, equipment maintenance, etc. So if not managed by the entire process of production system from the manufacturing process to the management area, final product sold to the customer cannot have a high quality [4]-[6]. To counter this problem, the authors designed a new monitoring system that can extract and visualize the critical information from the robot components. The robot working history as well as the current status can be instantly identified, hence more accurate and efficient robot management become possible. In this study, each function of the monitoring system is defined, as shown in "Fig. 1".

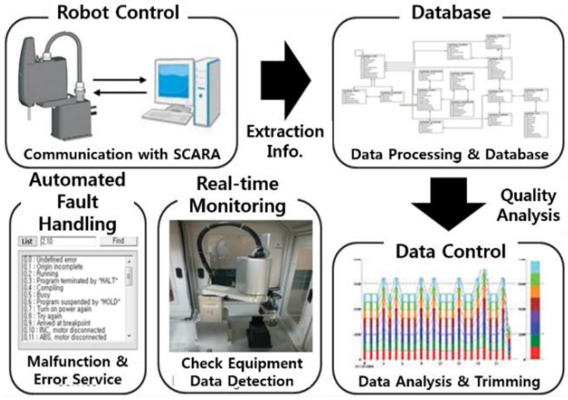

Figure 1. Monitoring system process

TABLE I. Three Systems of the Monitoring System

System	Function
Robot Control	-Robot-user communication, -Robot servo On/Off; Robot power control -Robot programming; Various calls for the data
Data Handling	-Extraction of called data -Robot moving distance -Robot motor rotation -Time data acquisition -Acquisition of motor rotation information
Real-time Monitoring	-Visual monitoring -Error Message List -User self-help function -Equipment replacement period

Robot Control System is to connect remotely to the SCARA (Selective Compliance Assembly Robot Arm) robots. This system performs the operation of robot, real-time control, robot programming, and data acquisition.

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Data Handling System saves the data into the database and analyzes and converts the extracted data into meaningful information. Once converted, it is provided to the operator through Real-time Monitoring System. Table I shows the detail.

II. Experimental Set-up

Before the design, as shown as "Fig. 2", the networked robot cell is configured with two SCARA robots, single-axis robot, robot controllers, pneumatic transfer devices, various sensors, network cameras, and LCD touch screens for operation. All major equipment has the IP address and it is possible to remotely control the robots through various script languages. Table II summarizes the type of data to be transferred from the work cell.

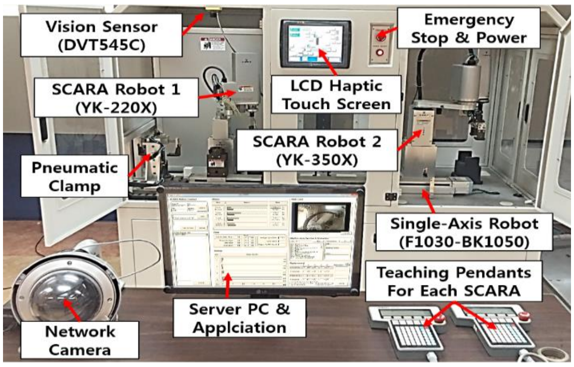

Figure 2. Robot work cell for the experiment

TABLE II. Type of Generated Data in Work Cell

Data type	Data source	Data format	Sampling Frequency
Image Data	Network camera	Color Image Frame	75 frames/sec
Quality Information	Vision sensor	Image/Numeric/Text	120 frames/sec
	Air Gauge	Numeric/Text	160 Mhz
	Touch Probe	Numeric/Text	250 bits/sec
	LVDT sensor	Numeric/Text	200 Hz
	Optical sensor	Numeric/Text	250 Hz
Equipment Status Information	PLC	Numeric/Binary/Text	9,600 bits/sec
	Robot controller	Numeric/Binary/Text	150 Hz
	Single-axis robot	Numeric/Binary/Text	50/60 Hz
	Pneumatic system	Numeric/Binary	200 bits/sec

In this study, the networked SCARA robots include X, Y, Z and R(rotation)-axis motors, three harmonic drives (the speed reduction gears installed in X/Y/R axes), one ball-screw drive (for Z-axis), pneumatic gripper, and the origin sensors. We developed the real-time monitoring system that extracts the critical data from those components and transform the data into more useful information. The information is visualized for the instant identification of critical process status, which can contribute to more accurate decision makings. The system also extracts time-related process data, such as gripper on/off count, servo running time, robot power on time, and idle/work/cycle time. All components inherit time class, then the time is measured and a number of equipment operation is counted. If any real or potential problems occur, the operator can easily know what's happening and make a timely and efficient decision as to the nature of the problem. The system can provide only the necessary information to the operator in a timely manner in an easily understandable format. In terms of process management, it can greatly improve the efficiency and economics of operations.

III. System Development

A. Robot Control System

In Robot Control System, we can control the SCARA robots through the development of network-based applications. Also, it is possible to share data between the respective components. "Fig. 3" shows the robot control process.

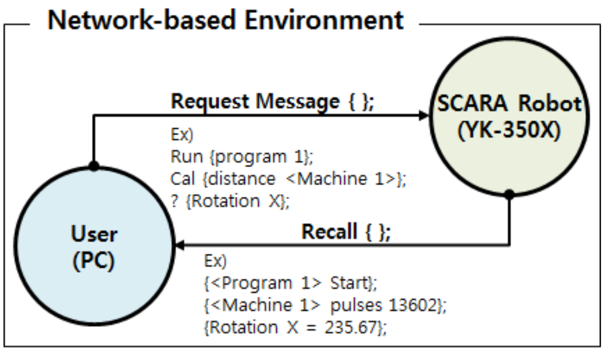

Figure 3. Robot control process

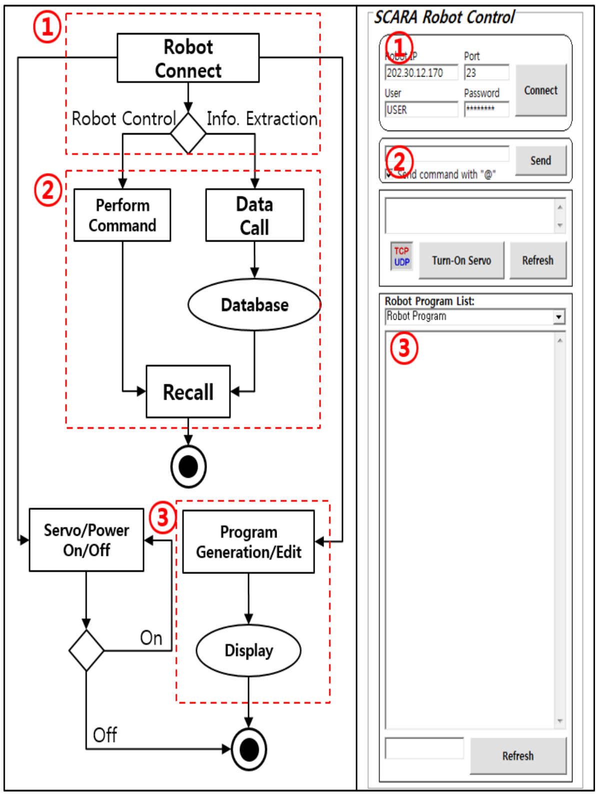

Figure 4. Robot control system structure

The system can obtain the data from the robot components. The operator is able to access the data, such as servo on/off, program execution/stop, robot status, robot moving distance, and program modifications. The data are extracted from the robot controller in real-time, as the program is being executed. Operator is able to call and examine the data, such as pulse values of each motor (X/Y/Z/R-axis). "Fig. 4" shows the structure of robot control system. In this study, the critical data from the motor components can be defined as follows: a number of rotations for each axis motor; a number of rotations for harmonic drives; and a number of revolution for Z-axis ball-screw device. Each time the robot is operated, the system extracts the robot movement values, in the form of 'Robot Pulse'.

B. *Data Handling System*

"Fig. 5" shows the process of Data Handling System, which converts the data into useful information. The most notable process information in this study is the number of revolutions for the motors and harmonic drives. To calculate the number of rotations for those, the 'Robot Pulse' values stored in the database for each axis have to be processed and transformed. For the SCARA robots used in this study, the resolver pulse values are predefined to describe one-full rotation for each axis. Additionally, the speed reduction ratio is also defined. Table III shows the reduction ratio and resolver pulse value per degrees of axis for the SCARA robot.

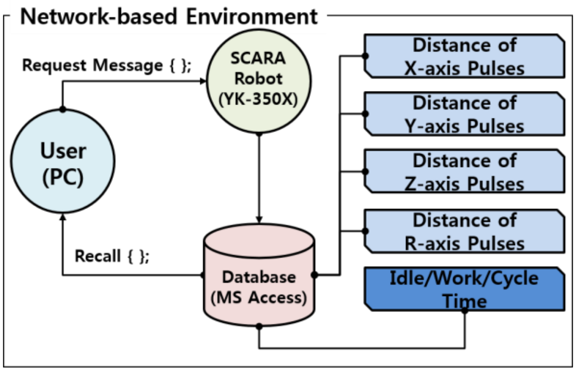

Figure 5. Data handling system process

TABLE III. SPEED REDUCTION RATIO FOR SCARA ROBOT

Axis	Speed Reduction Ratio(α)	Number of Resolver Pulses per 360 degrees	Number of Resolver Pulses per Lead Movement
X	50	819,120	N/A
Y	50	819,120	N/A
Z	12 (mm)	N/A	16,384
R	50	819,120	N/A

As shown in "Fig. 6", it processes the rotation and time data of motors and harmonic drives stored in the database. The results are graphically described and shown to the operator with the analytical chart, in order to facilitate the visualization. When the SCARA robots are working, the operator can obtain the moving distance and a number of rotation for each axis in real-time. Also, it updates information about working time, waiting time, cycle time, and counts the time whenever the motors of each axis operate. Accordingly, more efficient and timely decision making can be expected.

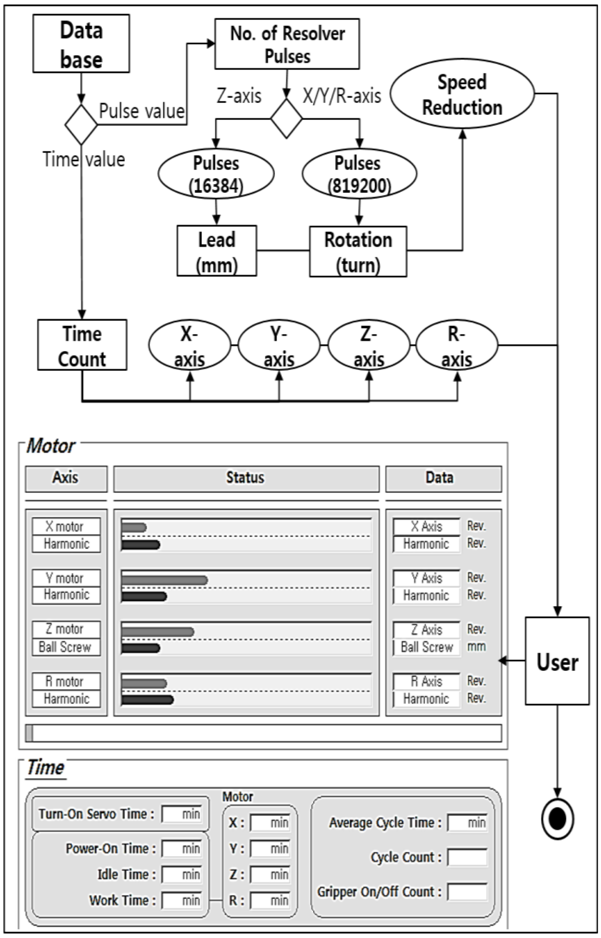

Figure 6. Data handling system structure

Prediction equations utilizing Transformation Matrix for rotational movement of the robot in two dimensional coordinates is in the form of "Eq. (1)":

$$\begin{vmatrix} Mx' \\ My' \\ Mz' \\ Mr' \end{vmatrix} = \begin{bmatrix} cos\alpha & -sin\alpha & 0 & 0 \\ sin\alpha & cos\alpha & 0 & 0 \\ 0 & 0 & \eta & 0 \\ 0 & 0 & 0 & \omega \end{bmatrix} \begin{vmatrix} Mx \\ My \\ Mz \\ Mr \end{vmatrix} \tag{1}$$

where *Mx'*, *My'*, *Mz'*, *Mr'* = coordinates converted through the rotational movement of the robot from *Mx*, *My*, *Mz*, *Mr* that are an initial coordinate of each axis. The values of η and ω are the conversion factor for each axis, and α is the angle of the first axis. When the first axis is moved, the second axis will change. Previous positional values can be defined as *xOld*, *yOld*, while the changed values can be define as *xNew*, *yNew*. The formula is as follows:

$$xNew = xOld + (Mx' - Mx) \tag{2}$$

$$yNew = yOld + (My' - My) \tag{3}$$

where β = the angle which moves the second axis of robot by using the acquired values *xNew*, *yNew*. Finally, the equation for calculating the final coordinates is as follows:

$$\begin{bmatrix} x_{final} \\ y_{final} \end{bmatrix} = \begin{bmatrix} cos\beta & -sin\beta \\ sin\beta & cos\beta \end{bmatrix} \cdot \begin{bmatrix} xNew \\ yNew \end{bmatrix} \tag{4}$$

These inverse kinematics requires Denavit-Hartenberg (DH) parameters. When moving the end effector, it is possible to calculate the L1 and L2:

$$L_1 = \left[(M_{x2} - M_{x1})^2 + \left(M_{y2} - M_{y1}\right)^2\right]^{\frac{1}{2}} \tag{5}$$

$$L_2 = \left[(M_{x2} - 0)^2 + \left(M_{y2} - 0\right)^2\right]^{\frac{1}{2}} \tag{6}$$

Additionally, it is possible to estimate the coordinates of B using the above-mentioned formula. However, this is a fourth-order equation, so the coordinate value of B is calculated as in the following "Eq. (7)-(11):

$$(M_{x2})_1 = [-B + (B^2 - 4AC)^{\frac{1}{2}}[2A]^{-1} \tag{7}$$

$$(M_{x2})_2 = [-B + (B^2 - 4AC)^{\frac{1}{2}}[2A]^{-1} \tag{8}$$

$$A = 4{M_{x1}}^2 + 4{M_{y1}}^2 \tag{9}$$

$$B = 4M_{x1}({M_{x1}}^2 + {L_2}^2 + {M_{y1}}^2 - {L_1}^2) \tag{10}$$

$$C = \left({M_{x1}}^2 + {L_2}^2 + {M_{y1}}^2 - {L_1}^2\right) - 4{M_{y1}}^2{L_2}^2 \tag{11}$$

In order to extract the angle θ that moved to the coordinates A' from A, utilize the slope of A~B, B~A' as S_1/S_2

$$\theta = \tan^{-1}\left[\frac{S_2 - S_1}{1 + S_1 S_2}\right] \tag{12}$$

C. Real-Time Monitoring System

Real-time Monitoring System integrates the two previously describe systems, namely Robot Control System and Data Handling System, in one application, and visualizes the entire operations of the robots in real-time. Consequently, it is possible to utilize only the necessary information as to the operational aspects of the networked robots. The system also displays any information regarding the equipment errors, whenever the error messages are generated by the robot controller. This is illustrated in "Fig. 7".

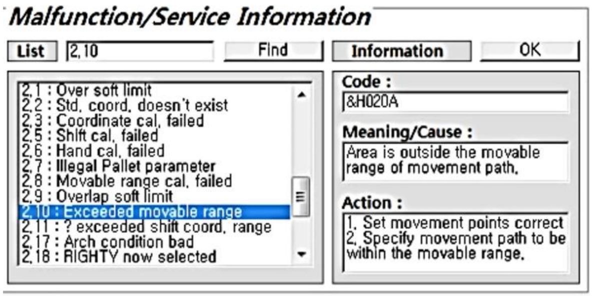

Figure 7. Real-Time monitoring system structure

The system classifies the error messages in accordance with the seriousness of the problem, and displays in the form of Major or Minor Malfunctions (see Table IV). In addition, operator can obtain the solutions to the problems in the form of short messages that are associated with each error message, which help identifying the cause of problem.

IV. Application Implementation

Through this visualization window, it is possible to know the critical information as to the robot operation, including the following: the robot control status; the workings of the motors and harmonic drives; process cycle time and other time-related information; the working history of robot components; robot malfunction data; live web-cam streams; and equipment maintenance information. Since the critical information is given in a single window, the operator can precisely understand the robot process information, which will ultimately lead to a better decision making process as to the efficiency and cost savings. As shown in "Fig. 8", the application allows the operator to check and confirm the workload of each axis motor. As shown in "Fig. 9", the application provides the analytical outcome of the robot operations, which should be available to the operator in terms of determining the proper time interval for the maintenance.

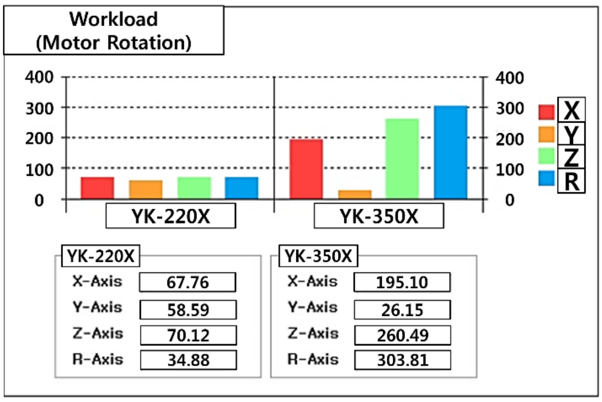

Figure 8. Analysis of the workload for SCARA robot.

Figure 9. Work-Related analysis of the SCARA robot.

V. Conclusion

The purpose of this study is to visualize the process information for the networked assembly robots through the Internet. In the past, the process information specific to the robots has not been readily available, hence any corrective actions or preventive maintenance have to be performed based on the inaccurate estimation.

To counter such problems, this study utilizes the advanced ICT technologies, in order to extract the critical data from the networked assembly robots. The data are then processed and provided in the form of visualized information to the operator. In other words, the operator can now properly observe and understand the past and current robotic working data during the entire process steps. In this context, more accurate decision making becomes possible through the availability of such information. It is expected that this will lead to more efficient robotic operations.

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