Sensor Fault Detection and Analysis of Fault Status using Smart Sensor Modeling

Sungshin Kim, Gyeongdong Baek, Soojin Lee, and Taeryong Jeon, *Member, KIMICS*

***Abstract*—**There are several sensors in the liquid cargo ship. In the liquid cargo ship, we can get values from various sensors that are level sensor, temperature sensor, pressure sensor, oxygen sensor, VOCs sensor, high overfill sensor, etc. It is important to guarantee the reliability of sensors. In order to guarantee the reliability of sensors, we have to study the diagnosis of sensor fault. The technology of smart sensor is widely used. In this paper, the technology of smart sensor is applied to diagnosis of level sensor fault for liquid cargo ship. In order to diagnose sensor fault and find the sensor position, in this paper, we proposed algorithms of diagnosis of sensor fault using independent sensor diagnosis unit and self fault diagnosis using sensor modeling. Proposed methods are demonstrated by experiment and simulation. The results show that the proposed approach is useful. Proposed methods are useful to develop smart level sensor.

***Index Terms*—**smart sensor, fault detection and diagnosis, level sensor, sensor modeling

I. INTRODUCTION

Recently as the semiconductor IC technology is generalized and micro sensor technology is developed, 'SMART' is used to sensor. Smart sensor refers to 'clear sensor', that is, 'intelligent sensor'. In the 1980s, micro-machining technology that has accomplishing fast development made usual massive fabricate sensor small silicone board such as semiconductor interchange and micro sensor available. It is available with interchange because it makes sensor in silicone board and combines with semiconductor circuit of amplification circuit, ADC/DAC, MCU, etc. These sensors are divided into general sensor and intelligence sensor that is 'Micro Smart Sensor'. The intelligence sensor is usually called 'Smart sensor'. Smart sensor combined micro sensor technology with semiconductor VLSI technology and also it has benefited by superior data processing ability of computer, judgment function, memory function, communication function, etc. Recently, as it concerned with ubiquitous technology. The concerns of smart sensor have certainly risen. Therefore, the intelligence sensor expands various applications of sensor which are smart home system, remote medical system, environment observer system, etc. as well as applications of general sensor. [1-5].

Many researches are progressing smart sensor technology to apply to level sensor. That is established in liquid conveyance, it shown that there is no completed product by smart sensor type in the inside and outside of the country about level sensor so far. There are some researches for sensor fault diagnosis that usually use Switching Kalman filter method [6], UIO (unknown input observer) method [7], modeling of buffer system method [8] and multidimensional wavelets network method [9] like mathematical method. And there is an algorithm which uses both the mathematical method and the artificial intelligence [16-18]. However, they did not yet have products of smart level sensor in Japan, the USA, and Europe even though they are front-runner in level sensor. They are still studying about smart level sensor. Also, a patent for smart level sensor technology could not yet find. Therefore, it is possible to make products with superior technology if we study and develop smart level sensor.

In this study, we proposed monitoring system for level sensor diagnosis which uses smart sensor technology in liquid conveyance. We proposed cargo monitoring system which consists steam pressure monitoring, cargo water level monitoring, over water monitoring, gas monitoring, and tank temperature monitoring. It is general control monitoring system which estimates its reliability and accuracy of transmission signal from each unit sensor system. And also this system does diagnosis of sensor fault and prediction of state.

In this paper, Section 2 describes the smart level sensor and Section 3 shows fault diagnosis algorithm. Section 4 shows the result of the algorithm.

II. SMART LEVEL SENSOR

A. Smart level sensor technology

One function of the smart sensor is about sensor self diagnosis which is developed in various sensors over inside and outside of the country. Angeli proposed the method about online fault diagnosis. In general fault diagnosis, they used mathematical method, artificial intelligence method and using both them. They described basis system of online specialist system which is used various algorithm for fault diagnosis [13]. Zhang Hongkun et al. proposed random fault diagnosis of sensor which is applied multi wavelet packet and energy

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value of signal. And then the fault is classified into multi wavelet network [9]. Zheng Shui-Bo et al. is developed prediction sensor model which is using ESP(electronic stability program) system to VM(support vector machines)[14]. Perla Ramesh et al. proposed a method of sensor assessment in delay dynamic system and this method verifies neural network and information fusion techniques. It was performed the detection, grouping and settlement about sensor fault by nerve general observation method [10]. Vemuri et al. studied the sensor fault diagnosis in nonlinear system and they developed the online estimated machine which used for estimated sensor fault through estimated nonlinear model and learning algorithm [11]. Paviglianiti et al. proposed sensor fault detection and classification method in a chemical reaction and also they assumed online security command using RBFN. They are classified the fault sensor and normal sensor by decision-making system [12]. It is sensor fault diagnoses in various fields. That is proposed diagnosis algorithms which are the fault diagnosis about 2 degrees of freedom [8] and the sensor fault diagnosis of chemical reaction [12]. It is difficult to give the sensor fault diagnosis and sensor fault state diagnosis because there is various sensors sin this study. There are some researches which are random sensor fault diagnosis [9], estimated sensor method of time delay dynamic system [10], and fault diagnosis of nonlinear system [11].

In this paper, we proposed the algorithm which is sensor self fault diagnosis and analysis of fault sate using sensor modeling.

B. Smart level sensor

In this paper, our proposed level sensor is a level transmitter sensor which is connected in a crude oil tank, a product tank, a particular liquid conveyance, etc. in cargo tank. This level sensor performs to send data to monitoring system by logging water level. The height information from the level sensor which is in the cargo tank is input to the control box and is sent to CRT monitor, printer or alarm etc. with the information from pressure sensor, confirmed sensor and other sensor. Figure 1 shows the line arrangement plan of smart monitoring system.

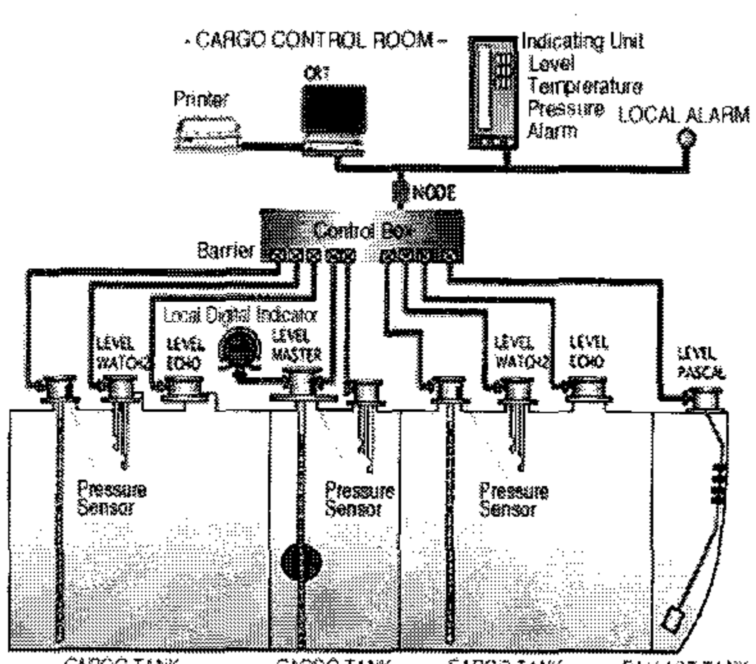

Fig. 1 The line arrangement plan of smart

C. Summary of smart level sensor

Smart level sensor needs to add the additional circuit which has the self diagnosis including microprocessor. In this paper, we designed the smart cargo sensor electronic circuit for analog signal and PCB in sensor module like figure 2. Figure 3 shows the block diagram of smart level sensor board. This shaded block diagram is smart level sensor board. Level sensor information exchanges the information for digital information by ADC built in PIC16F877A and exchanges the information of external monitoring system through RS232 communication. Figure 4 shows our experiment for Smart cargo sensor test. The equipment consist smart level sensor main board, smart level sensor housing of 2m height, plotting sensor module and monitoring system. We regulated the communication of each system using RS232 converter and regulated the water level inside level sensor using water pump.

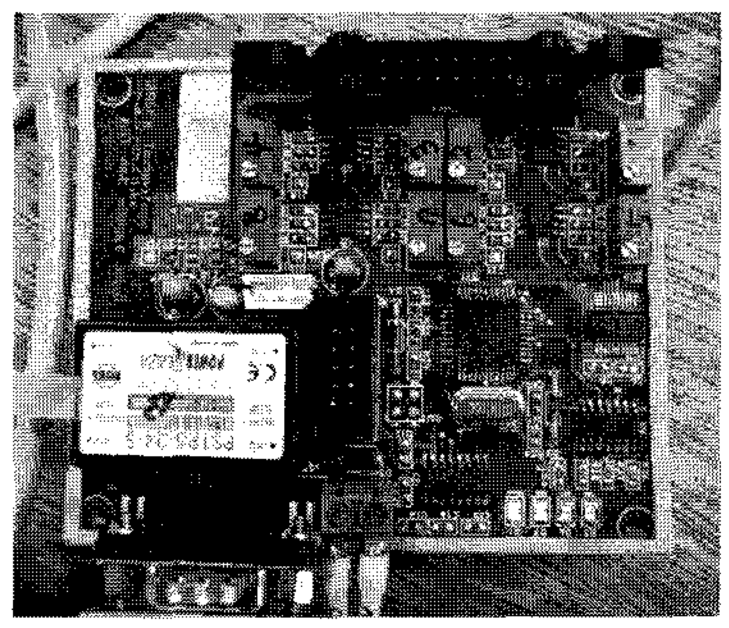

Fig. 2 Smart level sensor board

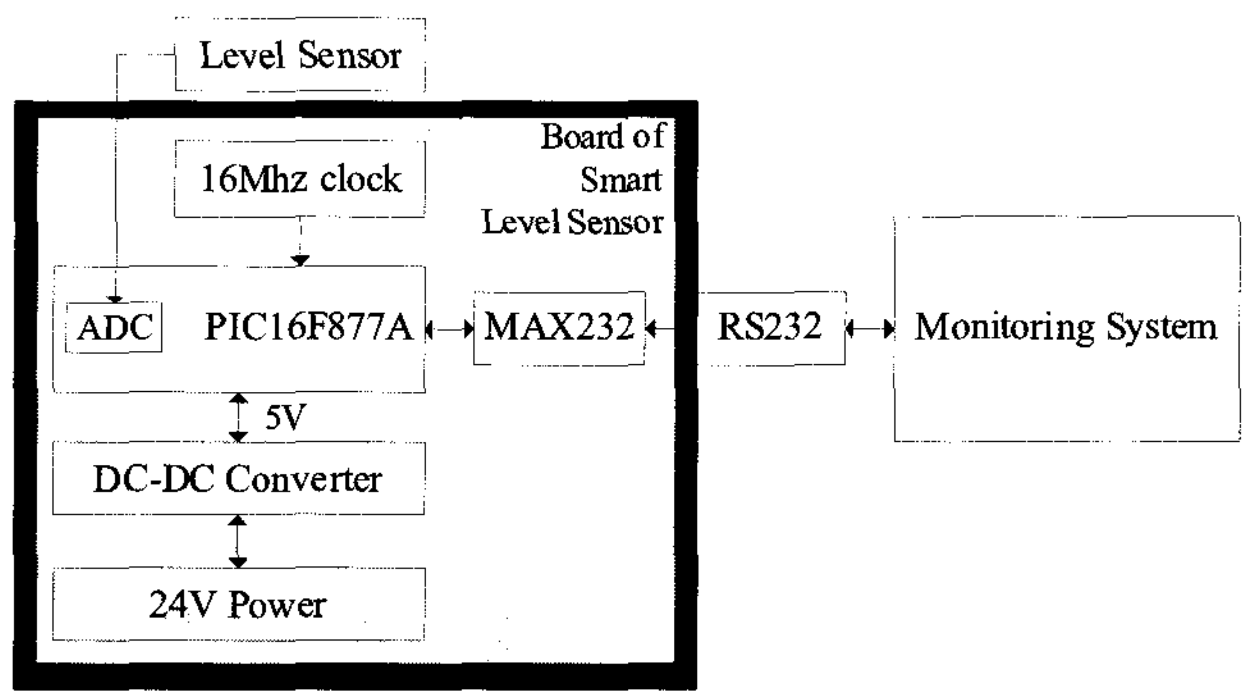

Fig. 3 The block diagram of smart level sensor board

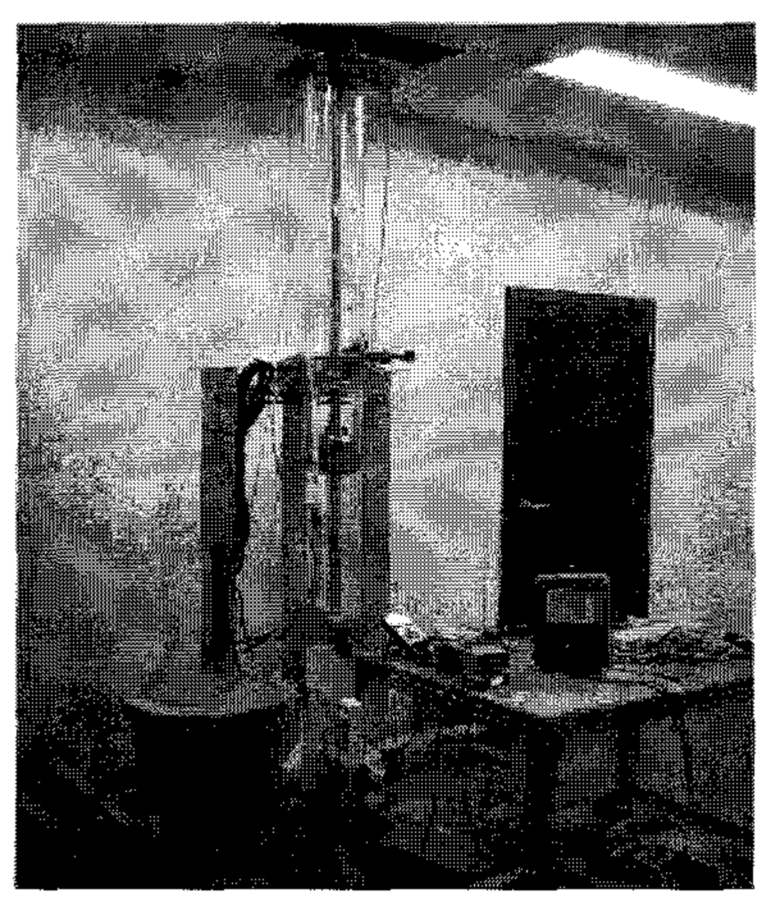

Fig. 4 Smart cargo sensor test

III. FAULT DIAGNOSIS ALGORITHMN

A. Sensor modeling of one sensor fault

First, we supposed that fault appeared in level sensor and the *n*-th sensor became fault in *k* sensors. This circuit diagram has one fault like figure 5. We proposed the equivalent circuit for the circuit diagram of figure 5. Figure 6 shows the equivalent circuit. There are the total *k* sensors and *n* has fault, V_{dc} of input voltage and V_{out} is output voltage.

In this case, V_{dc} is defined as follow:

$$V = \frac{200n}{-n^2 + kn + 80k} \tag{1}$$

Figure 7 shows Graph for output voltage and sensor position about the equation (1). The output voltage is formed the graph of monotonous increase.

This expression is defined about n:

$$n = \frac{-(\frac{200}{V} - k) + \sqrt{(\frac{200}{V} - k)^2 + 320 \times k}}{2} \tag{2}$$

We accepted the one solution value because the other solution has the negative value. We obtained the result that we can find the fault status if we substituted the voltage for the expression when we measured the fault voltage. Figure 8 shows the equation (2). We obtained fault sensor status by output voltage value.

B. Sensor modeling of two sensor faults

We can find the relative expression between fault status and output voltage if there were faults of two sensors. If we consider two faults which are *m*-th and *n*-th in *k* sensors, we obtain the circuit like figure 9. We derived the equivalent circuit for the relative expression and the result is figure 10.

In this case, V_{out} is defined:

$$R_a = \frac{1000(m-n)}{5(m-n)+200+200}$$
$$R_b = \frac{1000(m-n)}{5(m-n)+200+200} \tag{3}$$
$$R_c = \frac{40000}{5(m-n)+200+200}$$

$$V = \frac{1000(R_b + 5n)}{[5(k-m)+R_a][(R_b+5n)+(R_c+200)]+(R_b+5n)(R_c+200)}$$

We can obtain the output voltage of fault sensor status when we input the information of fault sensor status. We can also obtain the output value of possible fault using the equation (3).

C. Self fault diagnosis algorithm using sensor modeling

We obtained the output voltage of sensor status and we can derive the fault sensor status if we compare the normal output voltage with fault output voltage. Figure 11 shows the flowchart of diagnosis algorithm by sensor status of sensor fault. It consists of two part to sensor self fault diagnosis. First, we checked the value of 0m as an initial signal. If the value is 0m, the sensor doesn't have the fault. However, if the value is not 0m, the sensor has fault so we informed the fault and then start the process for fault status. The process shows the case which is same output voltage values of output voltage information and sensor log result. In this case, we can find the fault status information in output voltage of fault height. We can also diagnose the initial fault. Second, we can find the fault during the sensor action. We can find the sensor fault when the sensor value operation changed higher it. We supposed that the level of liquid is not changed highly water level in general level sensor.

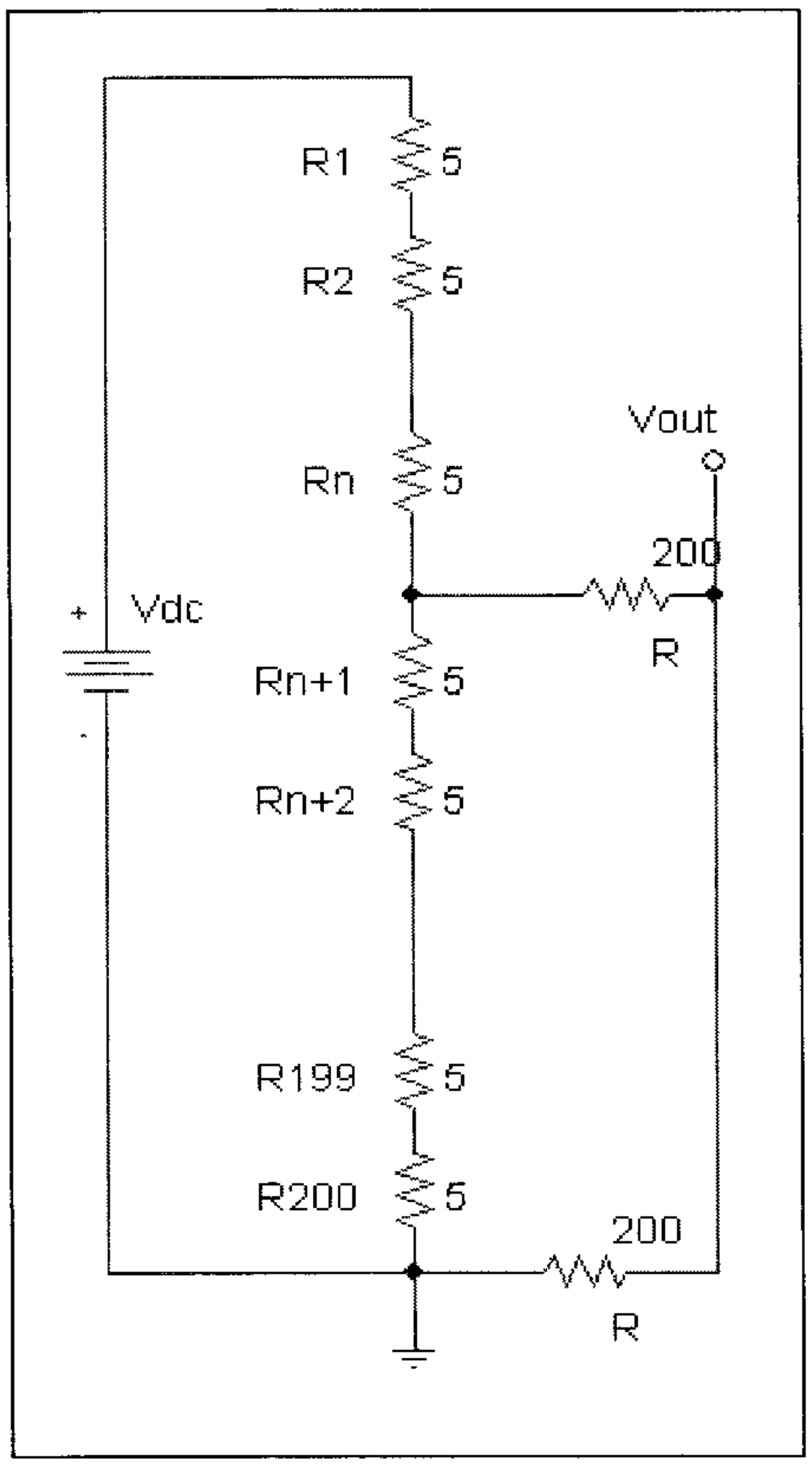

Fig. 5 The circuit diagram when the sensor has 1 fault

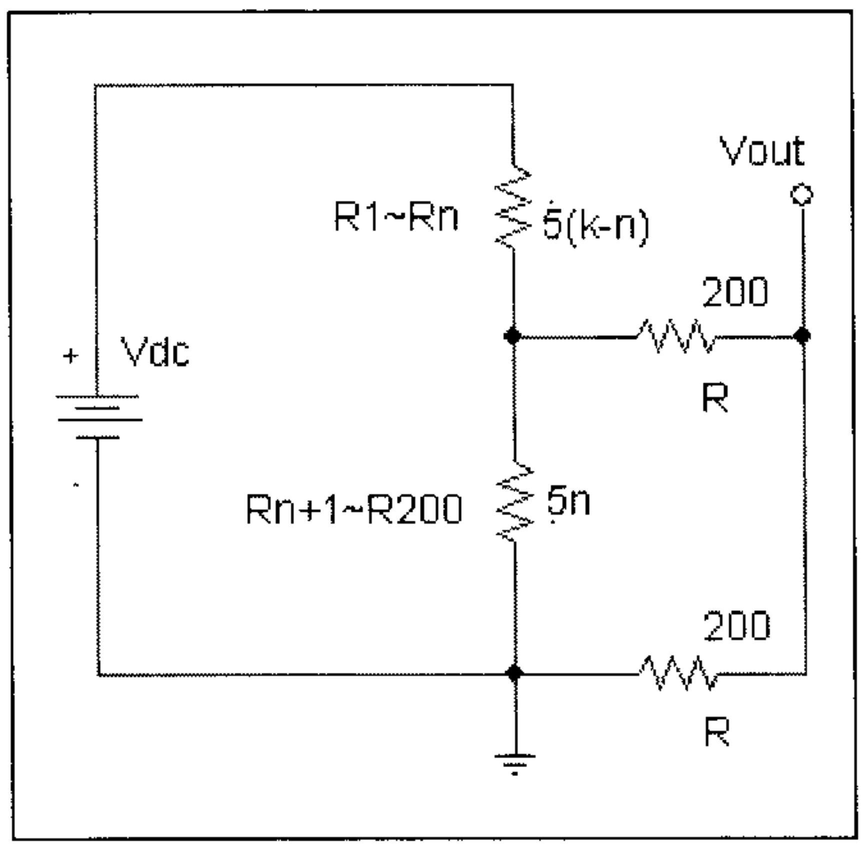

Fig. 6 The equivalent circuit diagram with Fig. 5

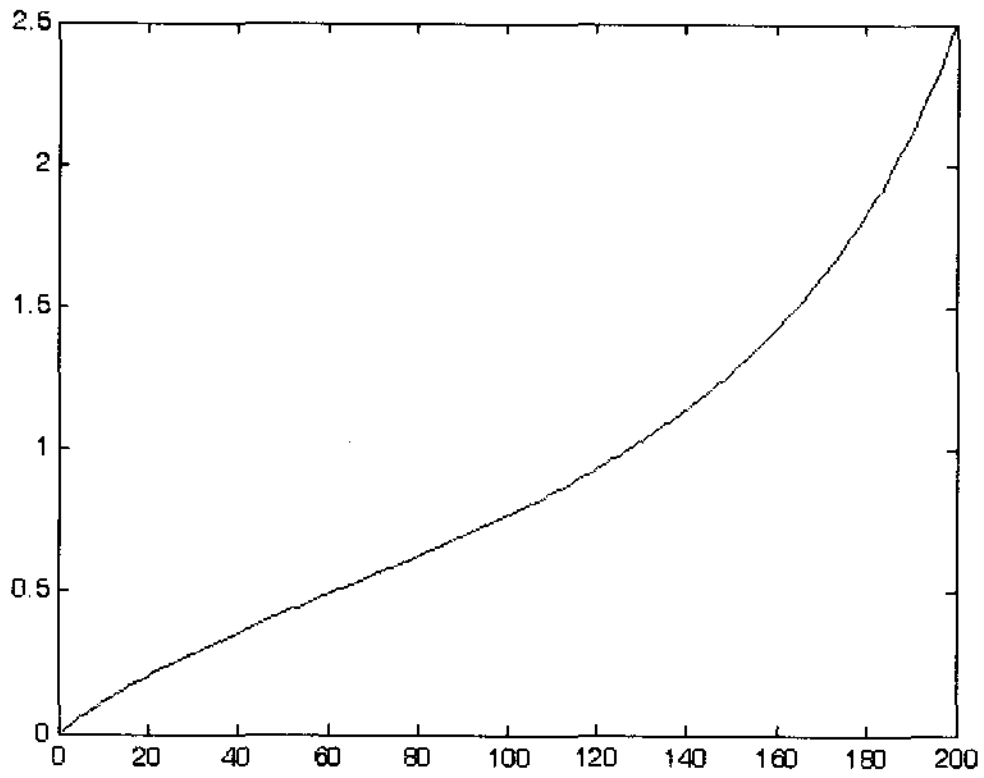

Fig. 7 Output voltage and sensor status of (1)

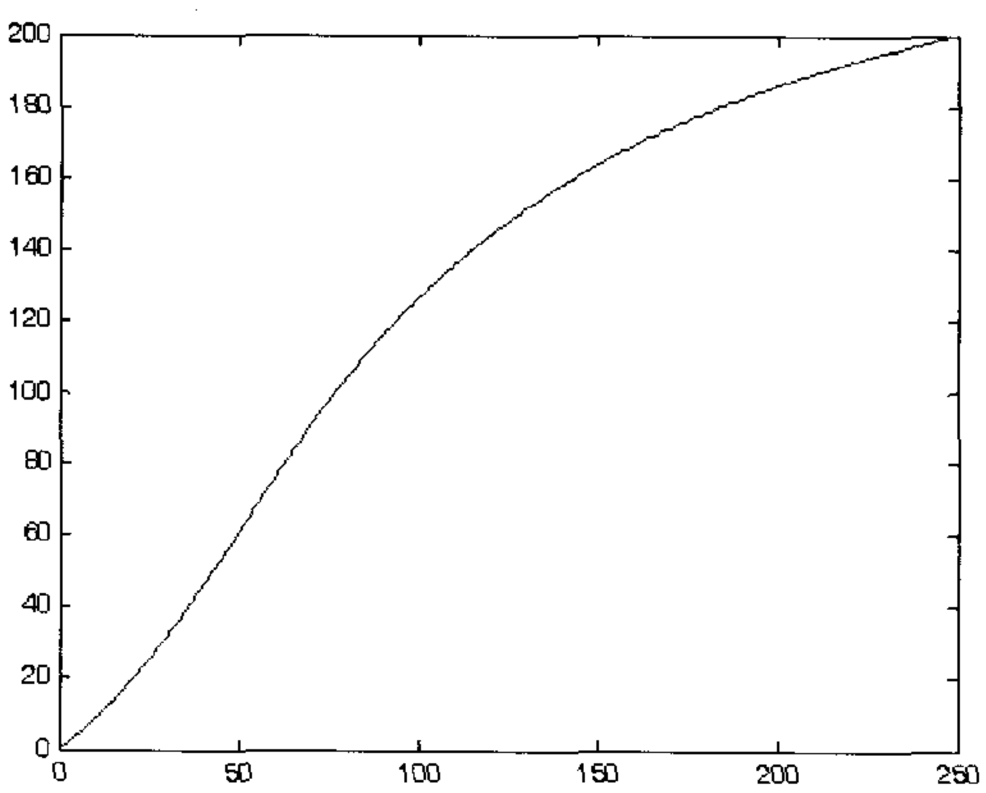

Fig. 8 Output voltage and sensor status of (2)

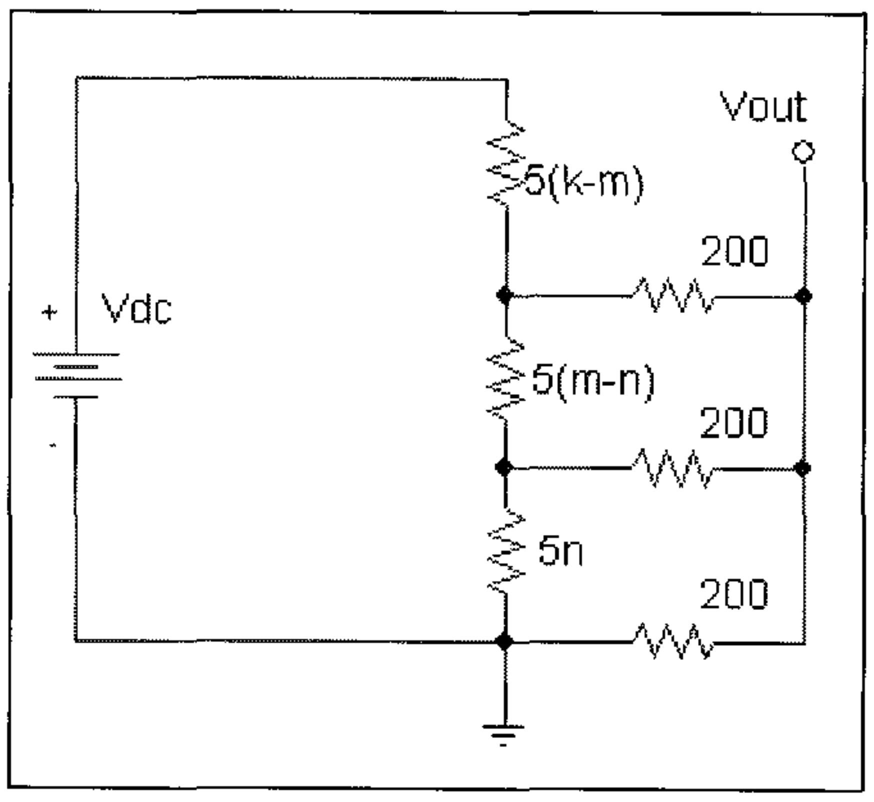

Fig. 9 The circuit diagram when the sensor has two faults

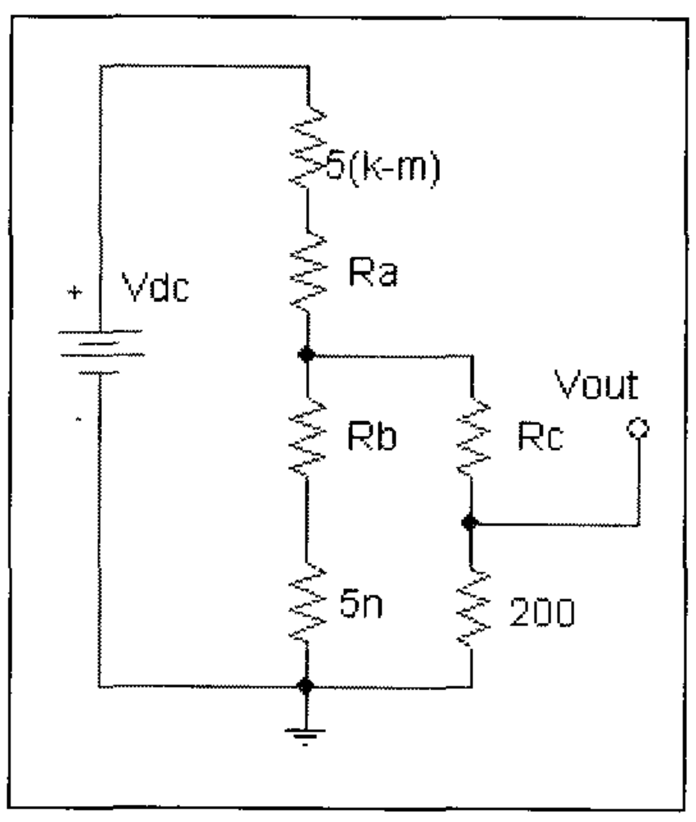

Fig. 10 The equivalent circuit diagram with fig. 9

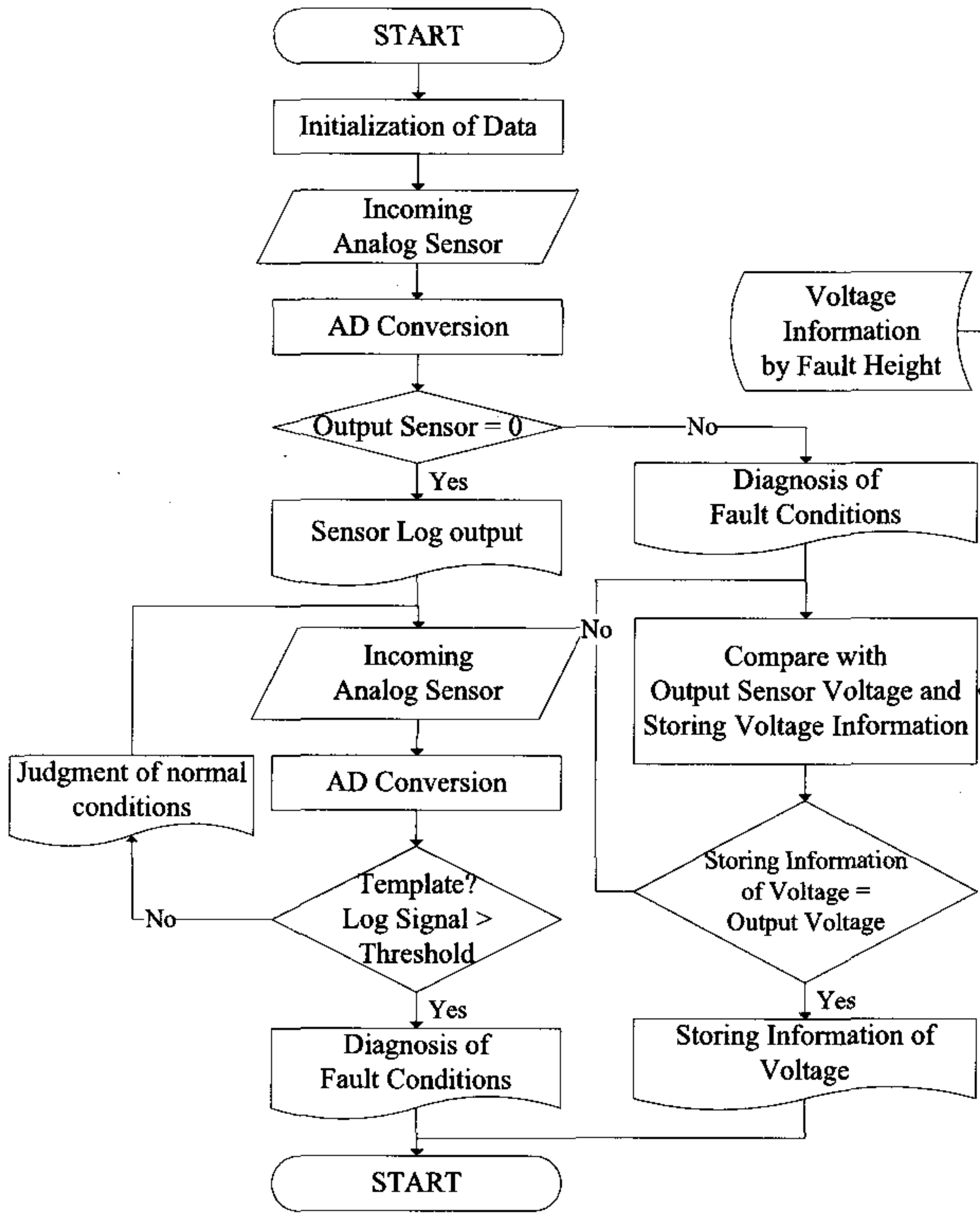

Fig. 11 Flowchart of diagnosis algorithm

IV. EXPERIMENTAL RESULTS

A. Simulation of one sensor fault

We obtained the useful result by simple algorithm that we found one height value per one output signal as figure 8. We found the sensor output using the equation (1) for the sensor output signal instead of real analog sensor value. Figure 12 shows the method of fault diagnosis simulation when the sensor has one fault. For example, we obtained the output voltage that is about $769mV$ by the equation (1) if $100th$ sensor was fault in 200 sensors. We found the fault status using the equation (2) because sensor status is natural number.

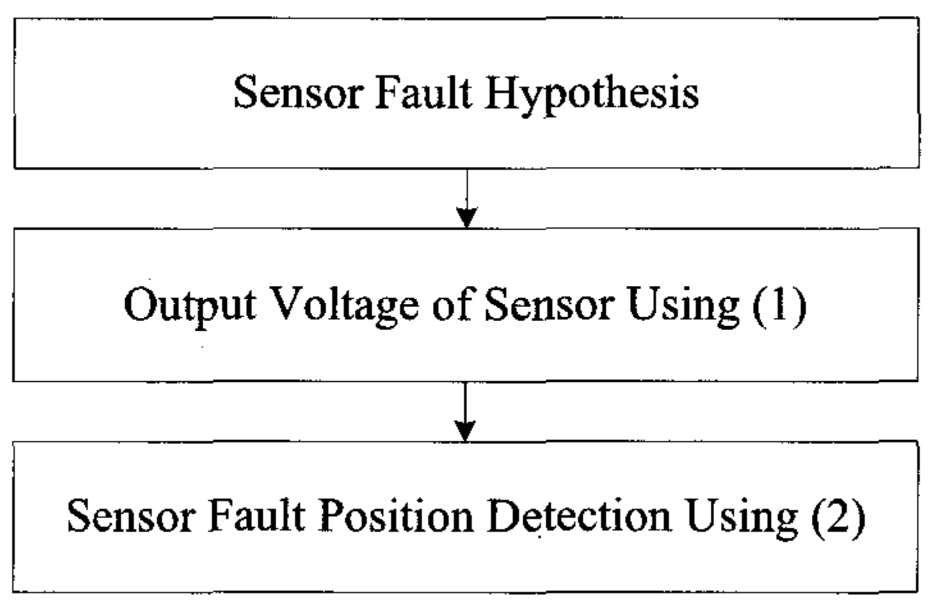

Fig. 12 The method of fault diagnosis simulation when the sensor has 1 fault

B. Simulation of two sensor faults

It is difficult to use fault diagnosis using the equation because it is difficult to derive the fault status about a log voltage in two faults. Therefore, in this case, we obtain output voltage on all occasions about two faults as the algorithm of figure 11. After that, we can define the estimated fault status by under limit value that is compared output voltage templates with real log voltage. For example, we obtained the $2.6271V$ using the equation (3) if $50th$ and $100th$ sensor were fault in 200 sensors. Figure 13 shows the graph for output voltage and sensor position when the sensor has 2 faults.

We obtained the sensor fault status about a log voltage. We can also find the log voltage and a crossing in over 2 faults case by case. We experimented on 199900 fault cases if it has 200 sensors 2 faults and obtained the limit value that is $125uV$. We found the same result it has the some fault status about all case.

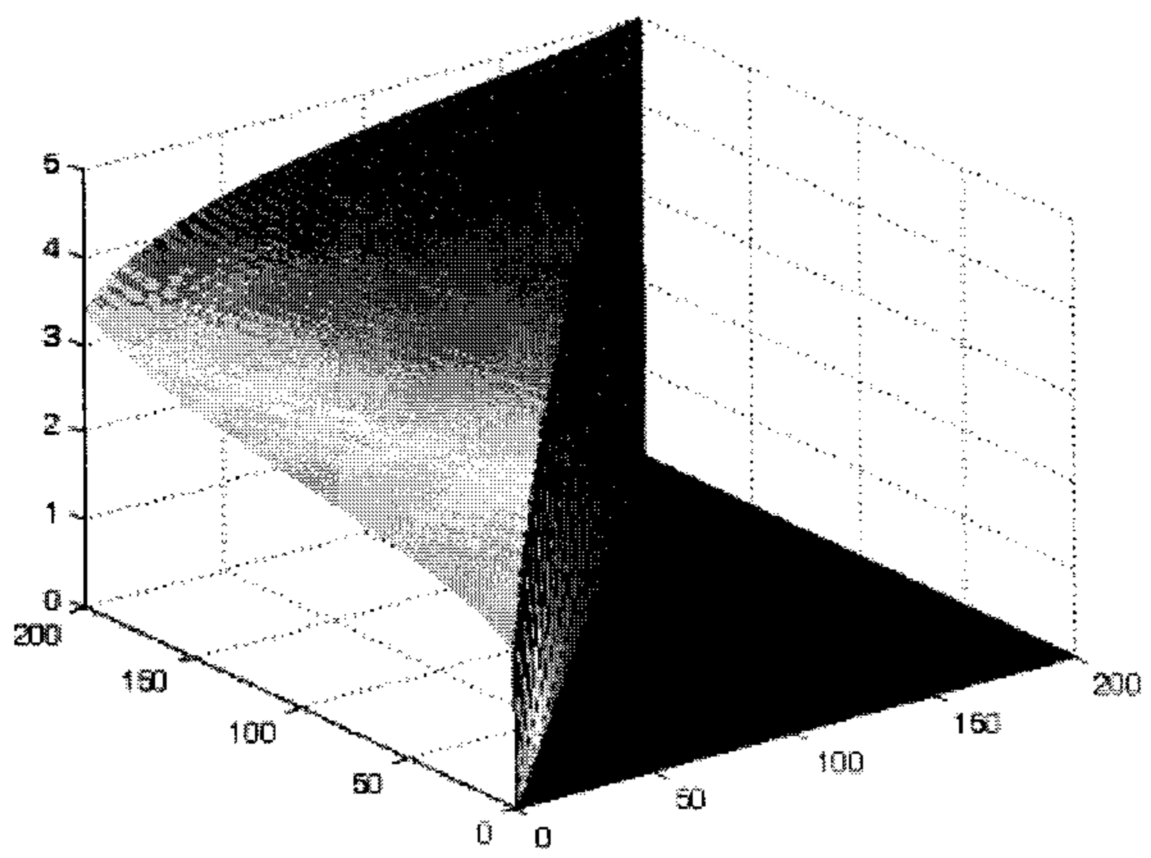

Fig. 13 Graph for output voltage and sensor position when the sensor has 2 faults (x axis and y axis means fault sensor positions, and z axis means output voltage)

V. CONCLUSIONS

The fault diagnosis about level sensor in the industry is important to save the time and cost in maintenance and repair of level sensor. It is also useful especially the industry to develop the smart level sensor including self diagnosis. However, the intelligence study of level sensor is not revitalized yet compared with other sensor study.

In this paper, we performed an algorithm development about independent sensor diagnosis which can do self diagnosis algorithm and sensor fault diagnosis for smart level sensor. We found the fault and moreover fault status using independent sensor diagnosis. And also we found the fault and fault status in simulation for proving self diagnosis algorithm. We can get the smart level sensor with more excellent performance through the proposed the self diagnosis algorithm in this paper.

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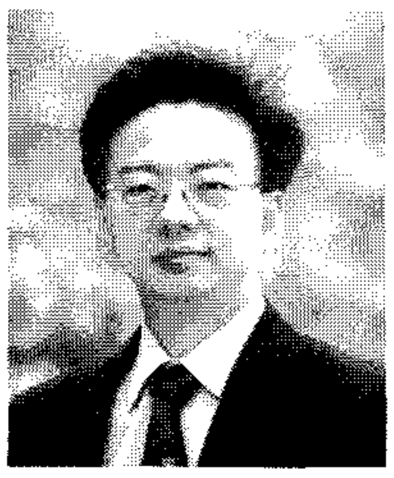

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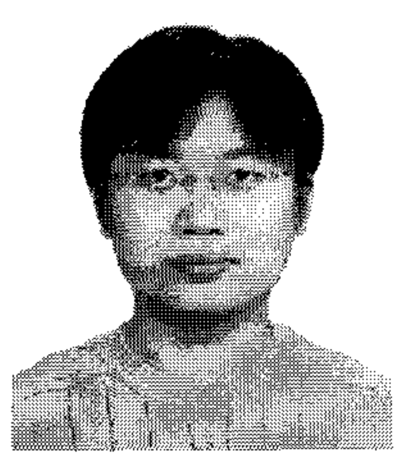

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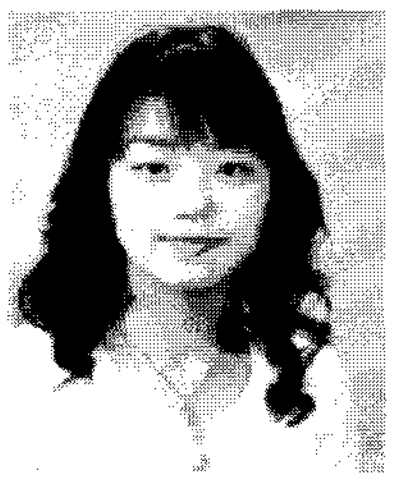

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