Abstract—In this study, a carbon nanotube (CNT) flexible strain sensor (CFSS) was fabricated with CNT based rubber composite for the strain sensing of structural health monitoring (SHM). The CFSS is a biomimetic flexible continuous strain sensor by means of piezoresistivity in CNT/EPDM (Ethylene Propylene Diene M-class) composite. For the application of CFSS of SHM, an artificial neuron network system (ANS) was developed using an array of CFSS for a signal processing system of the sensor and applied to a flexible membrane. Moreover, a strain positioning algorithm (SPA) was developed to find the localized strain information of ANS in Labview environments.

Keywords—Artificial neuron network system, Carbon nanotubes, Strain sensor, Structural Health Monitoring

I. INTRODUCTION

Structural Health Monitoring (SHM) is a technology that diagnoses and monitors the state of subject structures using various sensors. A development of SHM can prevent accidents by sensing the damages in structures and machines caused by natural disasters or decrepitudes and represent an expectation in reducing the cost of maintaining. However, it is difficult to apply it to large scaled structures due to the increase in the complex wiring and measuring cost according to its data processing as a large number of sensors are used to measure the damaged region of large and complex structures, such as bridges, buildings, ships, and etc [1][2].

In this study, we developed a carbon nanotube flexible strain sensor (CFSS) for improving the issues of using large number of SHM sensors, system complexity, and economy and an artificial neuron network system (ANS) [1][5] that is a signal processing system, which can process data using a small number of sensors for large regions, by fabricating the CFSS using an array type of membrane. Also, we developed a strain positioning algorithm (SPA) that estimates positions according to the strain of ANS in Labview environments.

II. FABRICATION OF CFSS AND ITS CHARACTERISTICS

A carbon nanotube flexible strain sensor (CFSS) was fabricated using rubber based nano composite materials with the EPDM (Ethylene Propylene Diene M-class) as a matrix material and the multi-wall nanotube (Aldrich, 677248) and nano clay (Southern Clay Products, Cloisite 15A) produced by using a composition method as conductive fillers, which represent a content ratio (wt%) of about 10%[3]. This composite material represents not only flexibility and electrical conductivity, but also piezoresistivity that makes possible to measure strain. Then, a flexible strain sensor was fabricated by cutting it with a proper length and that was connected to electrodes as illustrated in Fig. 1.

Six CFSSs, which were formed as a 3 x 3 lattice, were used to fabricate an artificial neuron network for estimating the position of detected signals according to the change in strains and that can be used as a system for estimating positions according to the change in external deformations. Also, a signal processing circuit was designed to process sensor signals presented by the change in strains. Fig. 2 shows the position pad for estimating signals detected from the deformation of the lattice type strain and its system configuration. the deformation of the lattice type strain and its system configuration.
Figure 1. CNT/EPDM Strain Sensor.
Flexible CNT/EPDM Sensor. (150mm × 6mm × 2mm, 123kΩ)
CNT/EPDM Strain Sensor (60mm × 3mm × 2mm, 90kΩ)

For implementing the study of the characteristics of CFSS, the response characteristics of CFSS for the strain and load were measured by attaching it to a cantilever. Fig. 3 and Fig. 4 represent the results of the measurement of the characteristics of the flexible strain sensors used in this study. Fig. 3 shows the tensile and compressive characteristics of the sensors for strains in which the CNT/EPDM strains represent a linear change for the tensile and compressive loads. Also, it showed no directionality for such tensile and compressive characteristics differed from the nano composite materials that apply solid polymer like epoxy as a matrix[1][3]. Fig. 4 shows the response time of the sensor for the amount of initial changes in which the rising time and time constant were measured by 0.4 and 0.2 seconds, respectively. Also, in the comparison of the results with a similar experiment that uses foil strain gauges, the CFSS showed a faster response, about 1.7 times, than that of the foil strain gauges. The results of such experiment were used to determine the sampling time and the number of sampling for the design of a position estimation algorithm for strains.

III. DEVELOPMENT OF ANS AND SPA

The ANS developed to implement a signal generation position estimation system based on the detection of the strain of CFSS was configured as an artificial neuron network using a type of lattice with three rows (sensor no.1, no.2, and no.3) and three columns (sensor no.4, no.5, and no.6). Also, as shown in Fig. 2, a wheatstone bridge, an amplifier (INA 128), and an RC filter(LPF), which is used to remove noise, were fabricated.

Figure 2. Experimental setup of the CNT/EPDM based flexible sensor to measure strain characteristics.

Figure 3. Strain response of the CNT/EPDM flexible sensor due to the piezoresistivity.

Figure 4. Response time of the CNT/EPDM flexible sensor.
The ANS represents intersection points due to the cross of the rows and columns of the CFSS. As concentrated loads occur at the surface will be detected by such intersection points of the CFSS, and then each CFSS outputs proportional voltage signals according to the strains as illustrated in Fig. 5. Here, the levels of the voltage generated by each CFSS are in proportion to the levels of the strength caused by the difference in the distance between loads.

In addition, a strain positioning algorithm (SPA) that estimates the generation position as real-time using the output voltage of the ANS according to the external force mentioned above was developed. For designing the SPA, it was fabricated by ensuring the reliability of the measured signals through obtaining the average of the output voltage values measured during the time constant determined in Fig. 4 in order to remove the noise occurred by the influence of surroundings. Also, it was designed to recognize the change in strains caused by exceeding the voltage of 6.3V that occurs as the output voltage of the CFSS approaches to the time constant for searching the location of the generation of external forces. As the sensors assembled at the position of the lattice structure detect the strains recognized by each CFSS and the output voltage values simultaneously, it represents the generation of strains at such points. As shown in Fig. 5, it was possible to improve the accuracy of the position estimation based on the difference of strength between the CFSS values with and without the generation of voltage values. By applying such developed SPA, as illustrated in Fig. 6, a program that implements signal processing and position estimation was developed in NI Labview environments as the concentrated loads occur at the surface of the ANS. By attaching LEDs at the lattice intersection points as shown in Fig. 6, the position estimation can be implemented at the assembled position of the CFSS 6 and 2, which represent the largest strengths, in which these LEDs were lighted.

IV. CONCLUSION

In this study, we developed CFSS that shows flexibility and piezoresistivity using CNT and rubber for applying it to SHM and studied its dynamic and static characteristics.

It was verified that the static characteristics of the CFSS in which the CFSS represents no directionality for the tensile and compressive loads based on the deformation test of the strains for such piezoresistivity, but the change was represented as a linear manner relatively. In addition, the sensor response time of the CFSS for the initial change showed a faster response, about 1.7 times, than that of the similar test, which uses foil strain gauges. By using the artificial neuron network system (ANS) that was developed to estimate the generation position caused by external forces by combining it with the signal processing for the signals measured at the CFSS and the strain positioning algorithm (SPA), it was possible to estimate the strength and position of the concentrated loads occurred at the surface of the ANS.

Regarding future study, it is necessary to develop a signal processing circuit that continuously outputs the output voltage of the sensor by compensating the electric variability of CFSS and to study on the distribution algorithm of the compression based on the measured strain values. In addition, based on the system presented in this study, it is expect to develop wearable sensors using the flexibility of CNT/EPDM composite materials and artificial robot skin for intelligent robots.

REFERENCES
