Soft-Computing Method for Detection of Abnormal Status of Plant Equipment

Seong-Joo Kim, Young-Joo Kim and Joo-Hoon Kim
Dae-Heung Industrial Gases Co., Ltd., Gunsan, South Korea
Email: {dh.sjkim, dh.yjkim, june24fly}@gmail.com

***Abstract*—Currently, the safety monitoring process in a complex plant environment is proceeded by the human. Sometimes, human error that may occur in a filed causes a severe problem. This paper introduces a soft-computing method for detection of the abnormal status of plant equipment using sound information and neuro-fuzzy theory that is one of the intelligent theories. The sound for testing is acquired from the cylinder valve, compressor operation, safety valve open. In this paper, the high-pressure gas filling plant will be used as a test plant. The resulting system will be widely applied to more complex plant environments.** [1]

***Index Terms*—safey monitoring, sound analysis, neuro-fuzzy logic, intelligence, detection**

I. Introduction

At the present plant, the safety checklists and status check logs are inspected and made by the person through the physical observation at the site. This tends to be due to human anthropomorphic judgments of physical phenomena, and it is difficult to maintain objectivity and consistency. Also, for this reason, it sometimes happens that an accident is caused by a person's mistake or illusion. In addition, it is very difficult to confirm facilities that are difficult to secure visibility at night or in a difficult access location. Therefore, it is possible to identify the problem by an empirical method for plant facilities that are less likely to be mistaken by such persons and difficult to physically approach.

In this paper, we propose the soft-computing model when a problem occurs in a plant. An expert can pay attention to the fact that it is possible to diagnose the phenomenon through sound information using auditory information so that even a novice or an unskilled person can use an algorithm.

It is possible to construct a database that can be compared under the same conditions by analyzing the sound characteristics that can be distinguished by the pre-recorded sound and the expert in the field and applying the post-processing technique. By applying this method to a fuzzy rule pre-built by a specialist based on the built database, it is possible to judge the normal operation of the plant facility using the real-time sound information in the field. In this paper, we will build a database using acoustic data that can be collected from industrial gas filling facilities, and build fuzzy logic by utilizing the expert knowledge of safety management for 20 years or more in the field. These results are compared with the actual situation of the plant facility by the experiment through the actual data.

II. Plant and Method

A. Target Plant Overview

There are various facilities that generate sound in gas filling plant facilities. Typical facilities include safety valves, compressors, pressure regulators, and valve seams. These facilities are characterized by a sound that occurs during normal, abnormal and dangerous operation. This can be used as a diagnostic element for environmental conditions that are difficult to be grasped visually by collecting sound information in the field.

The condition for these facilities varies from the design and purpose of use. For example, the safety valve has its original designated target pressure when it relief the gas inside for safety. Therefore, if the safety valve operates and a sound comes from the safety valve, an expert recognizes that something goes wrong in plant facilities. On the other hand, the compressor has its operation range between the minimum and maximum pressure. During the compressor operates among the operation range, the sound will be heard regularly, but if the compressor operates under the over the maximum pressure range, the irregular sound will be generated from the compressor.

In order to utilize this information, it is necessary to use the intelligent pattern recognition technique for applying the extracted information so that rules can be easily generated by extracting (recording) sound information on the field and preprocessing technology such as fast Fourier transform. After extracting characteristics, the fuzzy logic generated by a field expert will be applied for the inference of plant operation status.

B. Fuzzy Rules

We designate certain rules as fuzzy logic and apply them to the field. Unlike the general set, which indicates whether an element X belongs to the set A (1) or not (0), the fuzzy set is applied to situations where it is difficult to quantify because it represents membership values depending on how much the fuzzy set belongs. Thus, fuzzy logic treats fuzzy sets and fuzzy logic expressing uncertain or ambiguous elements as one quantity, and can

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express the relative importance of accuracy. In addition, fuzzy logic can be used as a basis for experts who fully understand the target system, and can be used in combination with existing control techniques [1-4].

The main goal of fuzzy logic is to develop systematic computational techniques and concepts to deal with approximate reasoning rather than to be correct. In fuzzy logic, the exact reasoning is the extreme concept of approximate reasoning. In fuzzy logic, It can be said that. Fuzzy logic is conceptually easy to understand, and has the advantage of being scalable to other problems besides the initial problem for any given system, and allowing a large range of inaccurate information [5] [6].

We set fuzzy rules based on the theoretical knowledge of the experts, field experience, and the acoustic information mentioned above. When the sound at the safety valve (Ss) is silent, the sound of the compressor (Sc) is constant, the sound of the regulator (Sr) is constant and the sound at the cylinder / globe valve is also silent, this means normal operation. (Ss) is low or the sound is fast at (Sc), or when the sound at (Sr) is also fast bass and the sound at the cylinder / globe valve is low, this means an abnormal operation.

Finally, when the sound at Ss is treble, the sound at Sc is also treble, the sound at Sr is fast treble, and the sound at the cylinder / globe valve is treble, which is dangerous [7].

The example of fuzzy rule is as follows.

- Rule 1 [safe]

IF (Ss is none) and (Sc is normal pattern) and (Sr is normal pattern) and (Sv is none), THEN the plant is safe.

- Rule 2 [abnormal]

IF (Ss is noise) or (Sc is abnormal pattern) or (Sr is abnormal pattern) or (Sv is noise), THEN the plant is abnormal.

- Rule 3 [dangerous]

IF (Ss is high level noise) or (Sc is unexpected pattern) or (Sr is unexpected pattern) or (Sv is high level), THEN the plant is dangerous.

C. Fuzzy Logic Design

For the normal operation of the target plant, arbitrarily set abnormal operation, and dangerous situation, the acoustic information is stored in the field through the high performance recording device, and analyzed by the acoustic analysis software. You need to extract the features to construct the database with sound of small and big sound and to set the truth value to apply it to the fuzzy rule.

First, the recorded sound signal is removed from the high frequency component higher than the sampling rate. The HPF (high pass filter) used to remove the high frequency components whose sampling rate is higher than 1/2 is expected to be used in the opposite way to the LPF (log pass filter) type filter. It is actually very difficult to be difficult. It is easy to implement low-frequency attenuation by LPF, but it is difficult to implement high-frequency attenuation by HPF. Nonetheless, the HPF form is often used to minimize distortion of low frequency oscillations.

LPF, on the other hand, is the basic form of all filters. It is implemented in the simplest form, and it is converted into various types based on this, and other kinds of filters are created. It is a filter structure that is often used to filter out high frequency noise signals and to select only the necessary signals of low frequencies. Then, the signal is sampled and quantized by an analog to digital converter (ADC), converted into a digital signal, and encoded, and the encoded digital information is edited, processed, and stored in a digital signal processor (DSP) for a desired purpose. The output is converted to an analog waveform via a digital to analog converter (DAC). This analog signal has less error due to lack of the sound information stored in some specific band (3dB bandwidth). In this paper, we propose a fuzzy rule based on the characteristics of each signal by building a database [8-12].

III. Model Design and Experiment

A. Fuzzy Inference Model Design

The process of transforming the digitized signal through the recording and processing of the acoustic information in the actual plant environment should be performed first. The fuzzy rules are generated through the acoustic characteristics database for the plant diagnosis built by the experts, and the fuzzy logic is combined with the information extracted from the field.

In this paper, we utilize a small plant facility that charges industrial gas, and conduct the situation judgment by the safety check standard through acoustic information collection. The target equipment was selected for the acoustic information collection, and the equipment was safety valve, compressor, regulator, valve.

There are two types of safety valves, 1.0MPa and 1.7Mpa, which are cryogenic storage containers. The compressor is a device for compressing gas with an operating pressure of 15 MPa. The inlet side pressure of the regulator is 0.7 to 1.0 MPa and the outlet side pressure is 0.3 to 0.5 MPa. The valves were selected for the valves of the gas cylinder vessel and the cryogenic globe valve. First, to define the situation in the field, the environment was created in an arbitrary state in order to implement the three conditions of normal operation state, abnormal operation state, and dangerous state. In case of normal operation condition, acoustic information is collected in the normal high pressure gas filling process. In case of abnormal operation, the safety valve is operated considering the overcharging condition of the container filling pressure. In the case of dangerous state, We have implemented the situation that is detected. This is expressed in a simple table as follows [13-15].

TABLE I. Condition for Decision of Operation Status

Status / Source	Normal	Abnormal	Warning
Safety V/V	silent	low tone	high tone
Compressor	constant	fast low tone	fast high tone
Cryogenic V/V	silent	low tone	high tone
Regulator	constant	fast low tone	fast high tone

As shown in the above table, in the case of normal operation, there is a phenomenon in which a certain pattern of sound is generated or silent. In the case of abnormal operation, there is a phenomenon in which the bass is generated or the pattern appears faster than the normal state. It is defined as the sound of each operation situation of the plant.

B. *Software and Hardware for Test*

Sound Forge 8.0 is an MS OS based application that allows you to record, analyze, edit and master digital audio. In addition, it can edit real-time files, and has a variety of professional-level effects and processes that can process different files while working on one file. By supporting various formats, Analysis can be done directly by looking at the sound. The ZOOM H5 Handy Recorder is a portable recording device that can record up to 4 tracks simultaneously with a built-in stereo microphone and two external inputs. It also has a sound input of up to 140dB SPL, and a shock mount device that suppresses handling noise. It has a built-in stereo microphone. It also has the advantage of being designed with a high voltage so that stereo images can be recorded without distortions. For the experiment, a safety valve (set pressure: 1.7MPa) installed in a cryogenic liquefied gas container was used to process the virtual environment in safety, abnormality, and dangerous state, and the safety valve was arbitrarily operated to extract the sound. For each state, we could obtain the results of analysis of sound wave, band(dB) and frequency (Hz) by Sound Forge software as shown in Fig. 1 ~ Fig. 9.

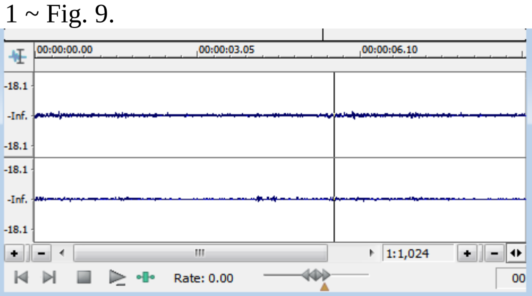

Figure 1. The wave of stable mode (Safety Valve)

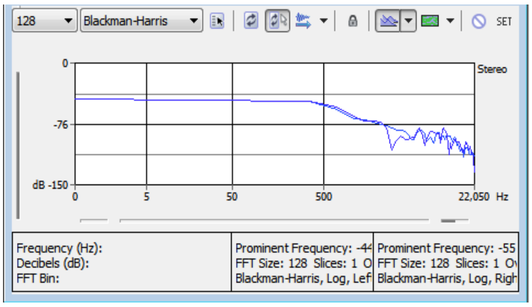

Figure 2. Analysis of the wave in stable mode(dB)

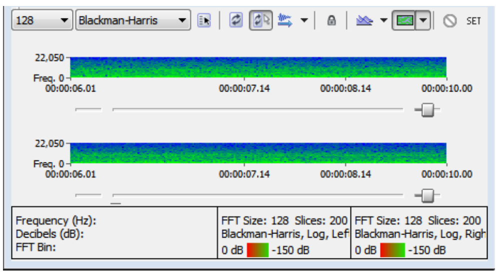

Figure 3. Analysis of the wave in stable mode(Hz)

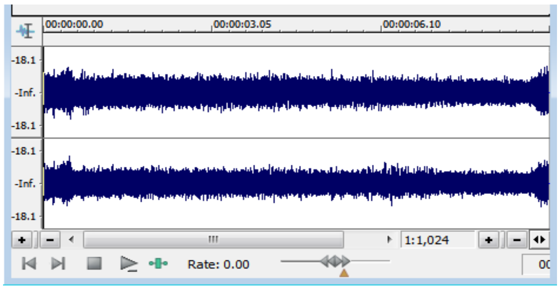

Figure 4. The wave of abnormal status(safety valve)

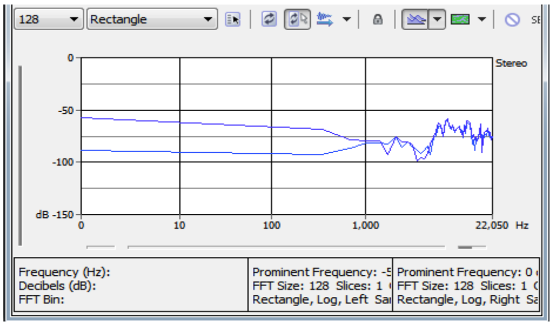

Figure 5. Analysis of the wave inabnormal mode(dB)

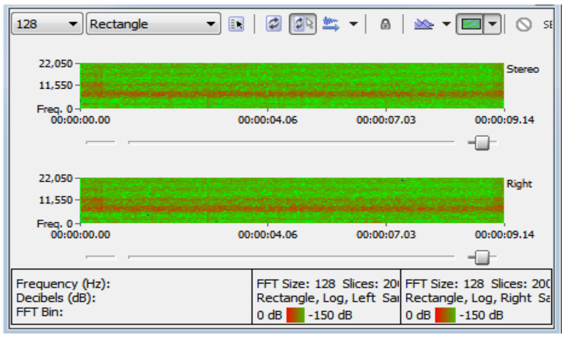

Figure 6. Analysis of the wave in abnormal mode(Hz)

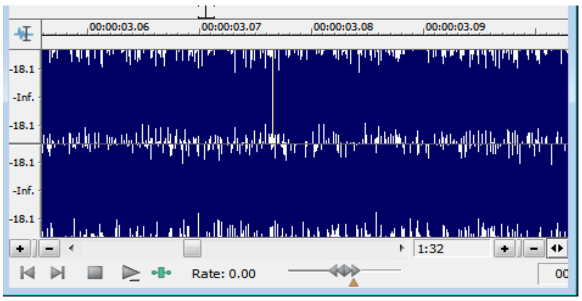

Figure 7. The wave in dangerous mode

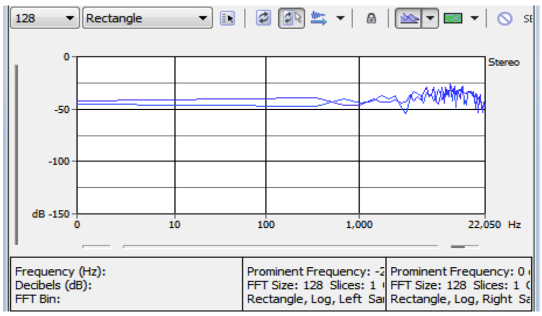

Figure 8. Analysis of the wave in dangerous mode(dB)

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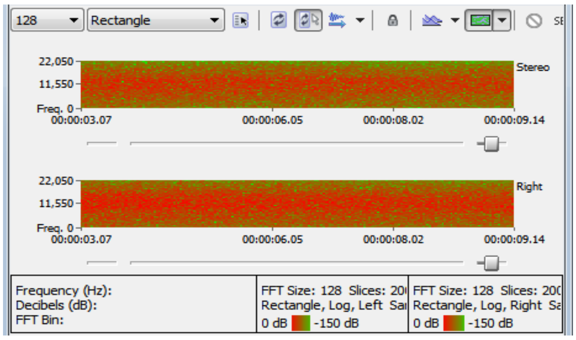

Figure 9. Analysis of the wave in dangerous mode(Hz)

The sound of the four devices of the target plant facility was investigated and analyzed. The frequency band and the waveform of the spectrum were different from each other. We applied this database to the fuzzy rule and succeeded in constructing it consistently, and we developed a diagnostic algorithm that can contribute to the prevention of accidents due to environmental awareness using auditory sense.

C. Fast Fourier Treansform and Fuzzy Input

From the result of Sound Forge software, we find the wave file has its unique bandwidth and frequency for each status of valve. We apply FFT(fast Fourier transform) for the wave file and get spectrum information and use it as an input for fuzzy model. The belows show the wave file of valve and results of FFT.

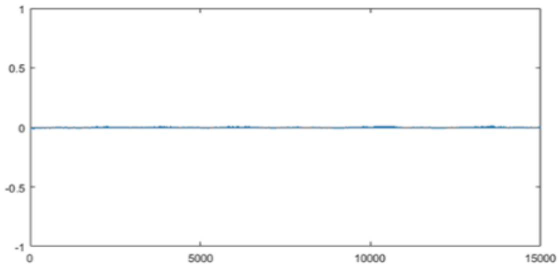

Figure 10. Sound wave of valve (normal status)

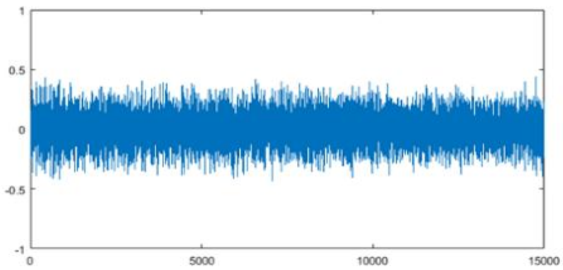

Figure 11. Sound wave of valve (abnormal status)

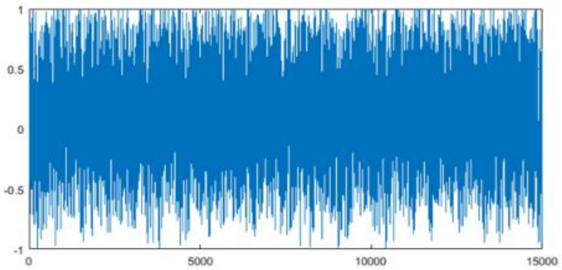

Figure 12. Sound wave of valve (dangerous status)

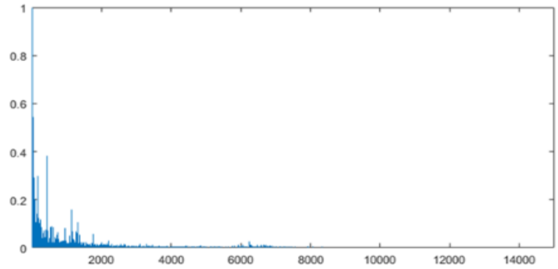

Figure 13. FFT spectrum of valve (normal status)

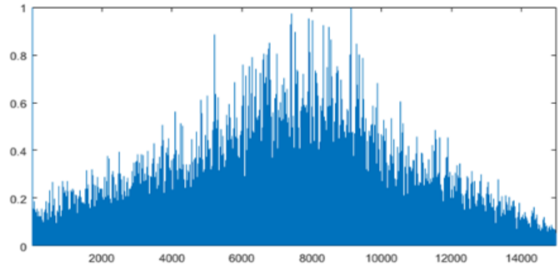

Figure 14. FFT spectrum of valve (abnormal status)

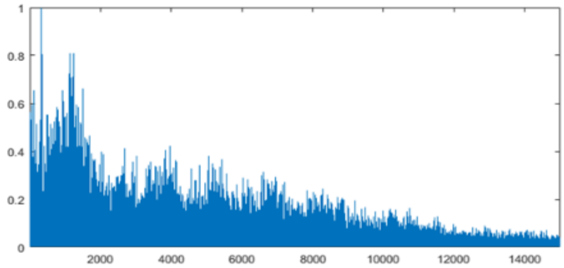

Figure 15. FFT spectrum of valve (dangerous status)

The FFT spectrum input determines the result of the fuzzy model. In both normal, abnormal and dangerous situations, the inferred state depends on the frequency range of the FFT spectrum. Fig. 16-18 show the threshold processed spectrum data for each signal.

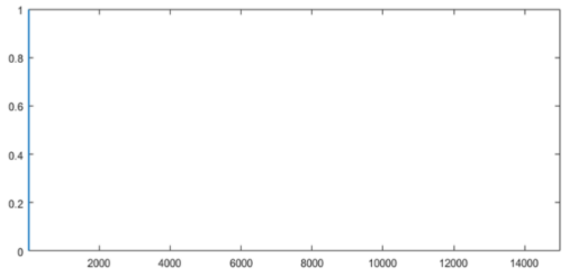

Figure 16. Threshold processed spectrum (normal status)

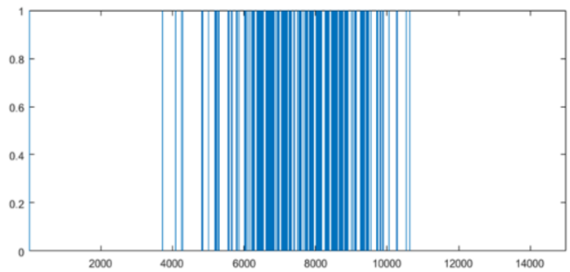

Figure 17. Threshold processed spectrum (abnormal status)

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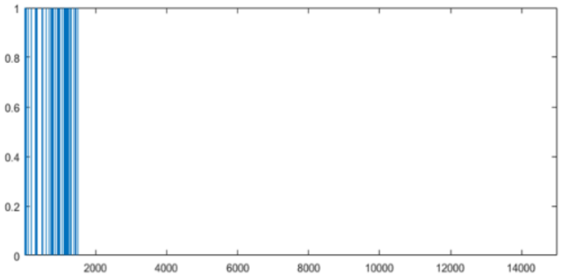

Figure 18. Threshold processed spectrum (dangerous status)

The threshold processed spectrum data is used to enter the fuzzy model and return the output according to the fuzzy membership function.

TABLE I. THE NUMBER OF EACH VARIABLE FOR EXPERIMENT

variable	number
nodes	204
linear parameters	100
nonlinear parameters	150
training data pairs	15000
checking data pairs	15000
fuzzy rules	50

In order to learn and infer the plant status automatically, we apply neuro-fuzzy model to the inference problem. The neuro-fuzzy model is generated by MATLAB software and the characteristic variables are set as follows. The overall neuro-fuzzy model is shown as follow.

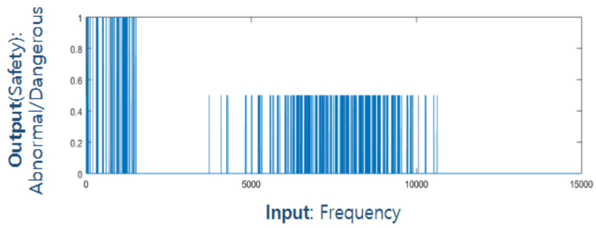

Figure 19. Fuzzy input and output

When the frequency is input to the neuro-fuzzy model as shown in Fig. 19, the results according to the system state are classified into normal, abnormal, and dangerous. We will learn the neuro-fuzzy model through the input and the results in Fig. 19. The variables used for learning are set as shown in Table I.

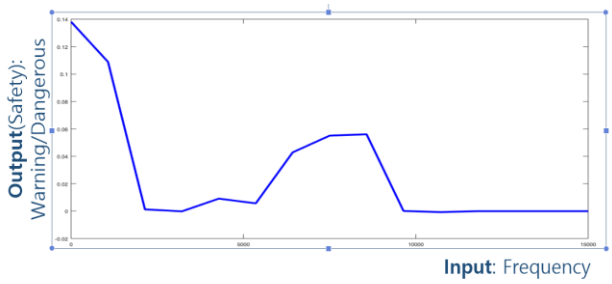

Figure 20. The result of neuro-fuzzy model

The Fig. 20 shows final inference result of neuro-fuzzy model.

IV. CONCLUSIONS

We used FFT, fuzzy rule base, and neuro - fuzzy model to judge and infer process status through sound of plant facility. As a result, it was possible to determine whether the equipment was abnormal when using the rules set by the experts. This can be used as a tool to prevent human errors and improve safety in plant facilities if applied to more complex environments. Strengthening noise areas in complex situations is a good way to detect risks in advance at various plant facilities.

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Seong-Joo Kim born in Gunsan, South Korea, 1971. He earned Ph.D. in control and automation, Chung-Ang University, Seoul, South Korea, 2004 and M.S. and B.S. in Electrical Engineering, Chung-Ang university, Seoul, South Korea, 2001, 1999, respectively.

He works as CEO at Dae-Heung Industrial Gases Co., Ltd. He worked in Seoul National University for pattern learning in gene information(2006~2007) and visited in Georgia Institute of Technology as a visiting scholar for studying about design of controller for micro aerial vehicle (2007~2009).

Dr. Kim is a reviewer member of IEEE Trans. on Vehicular Technology and a member of Korea Fuzzy and System Society.

Young-Joo Kim born in Gunsan, South Korea, 1974. He earned Diploma in sound engineering, Full Sail Institute, Orlando, FL, 2000 and MS in sound engineering, SAE Institute, Paris, France, 1998.

He works as CFO at Dae-Heung Industrial Gases Co., Ltd. He worked in Korea Broadcasting Services.

Joo-Hoon Kim born in Suwon, South Korea, 1980. He earned M.S. and B.S. in Electrical Engineering, Chung-Ang university, Seoul, South Korea, 2005, 2003, respectively.

He works as a senior researcher at Dae-Heung Industrial Gases Co., Ltd. He worked in Posco and Roboworks.

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