A study on vessel applicable indoor environment monitoring system

Gi-Do Choi[1] · O Chan Kwon[2] · Yang-Ick Joo[†]

Abstract: Recently, interest in indoor fine dust and indoor environment improvement has been increasing. Compared to land transportation, ships have a more restricted indoor environment owing to stability and space constraints. Due to the nature of the activities, such as, eating and moving on board a ship, if the indoor environment is polluted, exposure to that pollution can occur for a long time. Therefore, in this study, a vessel-applicable indoor environment monitoring system is developed that measures the indoor environmental values and communicates with the server using Wi-Fi. Further, to improve the reliability of the implemented system, an algorithm for removing the outliers in the data is proposed.

Keywords: Environment monitoring, Noise filtering, Ship indoor environment

1. Introduction

Recently, with the increased interest in indoor fine dust, the interest in improving indoor environments to maintain a comfortable indoor space is also increasing [1].

In accordance with the recent amendments to the Indoor Air Quality Management Act, the maintenance and management of indoor air quality in apartment houses and public transportation vehicles is regulated. In public transportation (buses and trains), the research on indoor environment measurement and measurement systems is being actively conducted; however, the research on ships is insufficient [2].

Compared to general structures including land transportation, it is essential for ships to maintain the confidentiality of the outer shell for water immersion protection and crevice wind protection because of stability and space restrictions. Accordingly, the indoor environment of ships can be exposed to pollutants for a long time [3].

Therefore, in this study, a ship-applied indoor environment monitoring system is developed that combines an indoor environment measurement system and a Wi-Fi-based data communication system.

This paper is organized as follows: Section 2 introduces the current indoor environment management standards based on the Air Quality Control Act and related systems applied to land transportation. In Sections 3 and 4, the design and performance evaluation results of the indoor environment monitoring system for ships are presented. Finally, concluding remarks are presented in Section 5.

2. Indoor Environment Management Standards and Related Systems

In the Indoor Air Quality Management Act for public facilities, indoor space pollutants are divided into five maintenance requirements and five recommended standards, and these pollutants are managed according to the relevant laws of the relevant ministries. **Table 1** shows the indoor air quality management status defined by the Ministry of Environment and Ministry of Health and Welfare [5].

Table 1: Indoor air quality management status by ministry

	the Ministry of Environment	the Ministry of Health and Welfare
Targets	- Public facilities - New apartment buildings - Public transport vehicles	- Public facilities(Performance hall, sports facility, etc.)
Related laws	- Indoor Air Quality Management Act	- Public Health Management Act
Obligation	- Air quality measurement and management - Obligation to comply with management standards - Staff training	- Obligation to comply with management standards

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Management items	- 10 items	- 4 items
Management method	- Local government inspection - Penalties for violations - Improvement order	- Local government inspection - Order for improvement in case of violation

Efforts are being made to maintain a comfortable indoor environment based on these management regulations, and various studies are being conducted on indoor environment monitoring for this purpose [3].

As an indoor environment monitoring technology for land transportation, the London underground and Siemens mobility provide indoor environment information through an in-train display after applying air monitoring and ride comfort monitoring to new railway vehicles currently operating in the London underground system [6]. Hyundai Rotem is developing a service that measures the fine dust, ultrafine dust, temperature, and humidity in a train and provides passengers with cabin congestion and fine dust figures [7].

3. System Design

3.1 System implementation

In this study, an IoT-based indoor environment monitoring system is designed. The system consists of a monitoring sensor module that collects real-time indoor environment information, a calculation and data processing module that analyzes information and transmits control signals, and a Wi-Fi-based communication module. Each sensor collects information about the indoor environment, integrates the collected information within the sensor module, and delivers it to the indoor environment integrated management module server through a wireless network.

Table 2: The collected information for each sensor

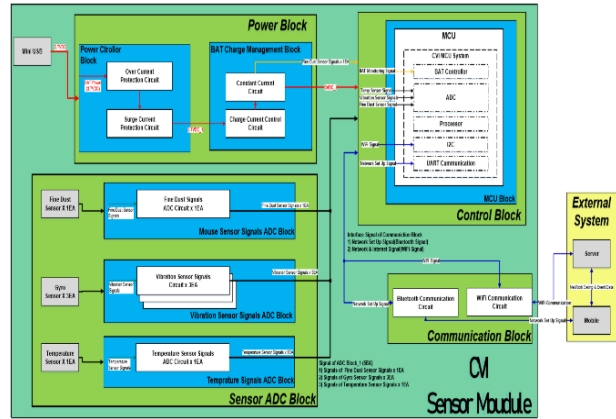|	Sensor	Specification
Temperature and humidity	HTU21D	– Digital out – Range: -40 ~ 80°C / 5 ~ 99% – Precision: ±3%
Fine dust	PMSA003	– Digital out – Range: 0 ~ 500 ug/m^3 – Precision: ±10%
Vibration	KXTJ3-1057	– Digital out – Range: 2G/4G/8G – Precision: ±0.1G
Noise	ICS43434	– Analog out – Range: -48 ~ 66 dB – Precision: 50 ~ 2 kHz

Figure 1: System architecture

Figure 1 shows the system architecture showing the overall operational flow of the system to be developed and the configuration of each module.

The measurement equipment for monitoring the indoor environment of a ship and maintaining and improving the indoor environment at an appropriate level must acquire data on indoor environment information (temperature, humidity, and fine dust) and indoor activity information (vibration and noise). The information collected from each sensor module is presented in **Table 2**.

3.2 Outlier removal algorithm

The actual indoor environment changes continuously at a slow rate. However, in the case of an indoor environment monitoring system in a ship, it is an environment in which the outliers are prone to occur because of challenges such as communication errors due to closed spatial characteristics.
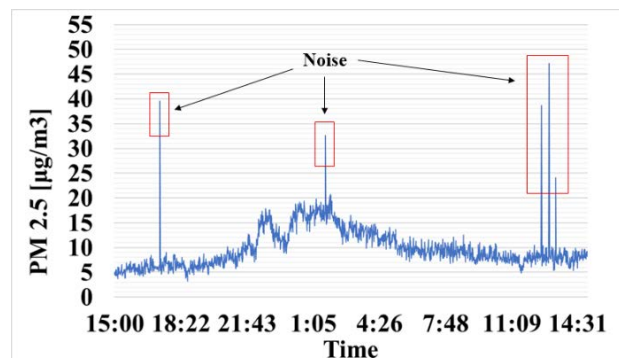

Figure 2: Collected signals and noises

Figure 2 shows the actual collected PM 2.5 (particulate matter less than 2.5) data. In this figure, the x-axis is time in minutes, and the y-axis is the concentration of PM 2.5. The overall signal

is stable; however, a signal with an exceptionally high transient value can be observed, as represented by the red box. The majority of these are communication errors that occur in the shielding environment of ships, which makes it difficult to monitor and manage the indoor environment through this system.

To address this problem, an outlier removal algorithm is proposed, as shown in **Figure 3**. The mean and standard deviation were calculated by statistically analyzing the data of the previous 24 h based on the measurement time, and the calculated statistical values were converted into a Z-score. Based on this result, it is determined whether the data at the current time point is normal or abnormal, and if it is abnormal, the outlier is replaced by a moving average filter.
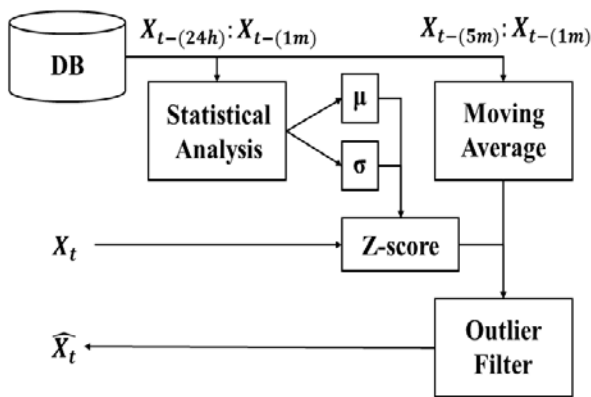

Figure 3: Proposed algorithm

Using **Equation (1)**, the Z-score value Z_t can be derived.

$$Z_t = \frac{X_t - \mu_{(24h)}}{\sigma_{(24h)}} \tag{1}$$

where, X_t is the air condition at time t, $\mu_{(24h)}$ and $\sigma_{(24h)}$ are the mean and standard deviation, respectively. Z_t becomes a criterion for filtering, as shown in **Equation (2)**.

$$\widehat{X_t} = \begin{cases} \overline{X_t}, & Z_t \geq threshold \\ X_t & Z_t < threshold \end{cases} \tag{2}$$

The estimation value of **Equation (2)** is determined through the threshold, and X_t is the moving average.

4. Experiment and Performance Verification

4.1 Proposed algorithm feasibility analysis

To verify the validity of the proposed outlier removal algorithm, it was compared and analyzed with widely used IQR and
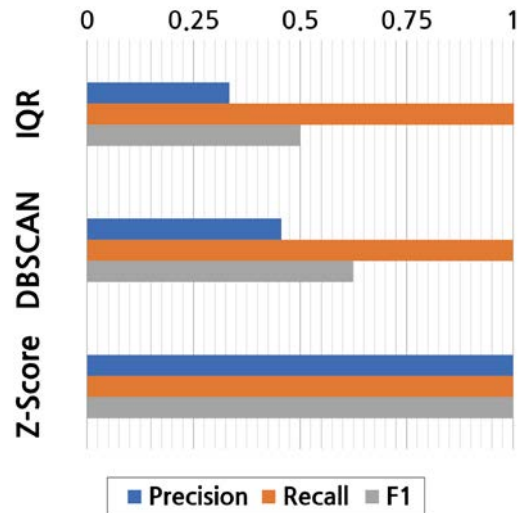

Figure 4: Comparison of accuracy by method

DBSCAN **[8, 9]**. The experiment was based on the data collected for a single day by installing the actual equipment on the ship. As shown in **Figure 4**, the Z-score applied in this study displayed the best accuracy.

4.2 Performance verification

To evaluate the actual performance of the proposed indoor environment monitoring system, it was installed in an actual vessel environment, and experiments were conducted.
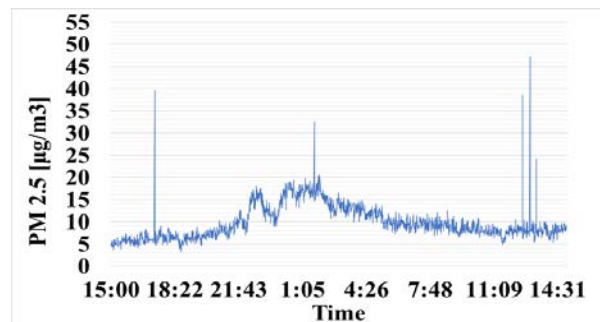

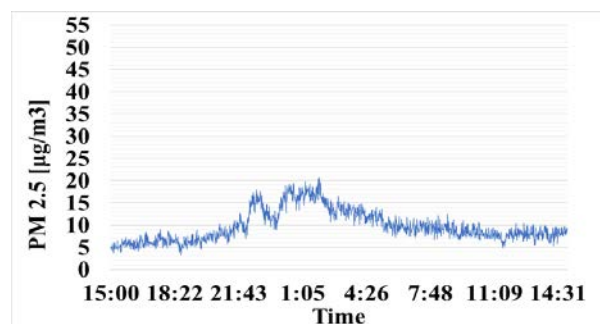**Figure 5:** The measurement data of PM 2.5 (raw data)

Figure 6: The measurement data of PM 2.5 (filtered data)

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Figure 5 and **6** show the raw measured data of PM 2.5 and the same filtered result, respectively. It can be seen that the outliers generated in **Figure 5** are all removed as a result of the filter in **Figure 6**.

5. Conclusion

In this study, an indoor environment monitoring system and an outlier removal algorithm to minimize noise for the efficient management of indoor air quality in ships was proposed. To verify the performance of the proposed system, it was installed on an actual ship, and the experimental data were collected. The experimental results confirmed that the proposed system can be operated in a ship environment.

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Author Contributions

Conceptualization, Y. -I. Joo ; Methodology, G. -D. Choi and Y. -I. Joo; Writing-Original Draft Preparation, G. -D. Choi and Y. -I. Joo; Validation, G. -D. Choi, O. C. Kwon and Y. -I. Joo; Writing-Review & Editing, G. -D. Choi and Y. -I. Joo.

References

[1] J. Y. Kim, Design and Implementation of Automatic Control System with Indoor Environment Monitoring Based on Internet of Things, M. S. Thesis, Daegu University, Korea, 2006 (in Korean).

[2] S. Lee and J. K. Lee, "Visualization of the comparison between airborne dust concentration data of indoor rooms on a building model," Journal of the Korean Housing Association, vol. 26, no. 4, pp. 55-62, 2015 (in Korean).

[3] G. Y. Doe, H. S. Lee, Y. G. Lee, and H. K. Lee, "A study on indoor air quality in new ship," Journal of Korean Navigation and Port Research, vol. 31, no. 5, pp. 427-434, 2007 (in Korean).

[4] C. Cho, Y. Jeon, K. Kwon, J. Seo, H. Park, S. Oh, and I. J. Chung, "IoT-based real-time air quality measurement system in residential environments," Korea Intelligent Information System Society, vol. 201, no. 8, p. 133, 2017 (in Korean).

[5] T. W. Kim, Y. K. Yang, M. Y. Kim, J. W. Moon, and J. C. Park, "Development of 'Internet of Things' based indoor environment measurement sensor module," Journal of Korean Society Living Environment System, vol. 26, no. 1, pp. 92-100, 2019 (in Korean).

[6] M. Stone and E. Aravopoulou, "Improving journeys by opening data: the case of Transport for London (TfL)," The Bottom Line, vol. 31, no. 1, pp. 2-15, 2018.

[7] M. Kozłowska, "MEDCOM exports and wins new global markets," TTS Technika Transportu Szynowego, vol. 25, 2018.

[8] H. P. Vinutha, B. Poornima, and B. M. Sagar, "Detection of Outliers using Interquartile Range Technique from Intrusion Dataset," Information and Decision Sciences, Springer, Singapore, pp. 511-518, 2018.

[9] K. Khan, S. U. Rehman, K. Aziz, S. Fong, and S. Sarasvady, "DBSCAN: Past, present and future," In the Fifth International Conference on the Applications of Digital Information and Web Technologies (ICADIWT 2014), IEEE, pp. 232-238, 2014.