Vol. 3, No. 1, June 2024, pp. 31-36
p-ISSN: 2963-8577
e-ISSN: 2964-3511
DOI: 10.57102/jescee.v3i1.80

JESCEE
Journal of Emerging Supply Chain, Clean Energy, and Process Engineering

MONITORING CO_2 AND SO_2 EXHAUST GAS EMISSIONS ON TANKER SHIPS WITH AN IOT-BASED PLC CONTROLLER

Iqbal Nur Fajar [1], Soni Prayogi[1*]
[1]Department of Electrical Engineering, Faculty of Industrial Engineering, Universitas Pertamina

Abstract
The increasing focus on environmental sustainability has necessitated the implementation of advanced technologies for monitoring exhaust gas emissions in maritime operations. This study presents the development and application of an IoT-based Programmable Logic Controller (PLC) system for monitoring CO_2 and SO_2 emissions on tanker ships. The proposed system integrates sensors, a PLC, and wireless communication modules to continuously measure and report emission levels. The sensors detect concentrations of CO2 and SO2 in the exhaust gases, transmitting real-time data to the PLC. The PLC processes this data, which is then relayed via IoT networks to a centralized monitoring station. This setup allows for timely detection of emission levels exceeding regulatory limits, facilitating prompt corrective actions. Field trials conducted on several tanker ships demonstrated the system's reliability and accuracy in harsh maritime environments. The implementation of this IoT-based monitoring solution not only ensures compliance with international maritime emission standards but also enhances the operational efficiency of the vessels by providing actionable insights into engine performance and fuel consumption. The study concludes that the integration of IoT and PLC technologies offers a robust, scalable, and cost-effective approach to environmental monitoring in the maritime industry, promoting sustainable shipping practices.

Keywords:
Exhaust gas emissions; environmental monitoring; internet of things; PLC controller

Article History:
Received: May 22nd, 2024
Revised: June 3rd, 2024
Accepted: June 21st, 2024
Published: June 30th, 2024

Corresponding Author:
Soni Prayogi
Department of Electrical Engineering, Universitas Pertamina, Indonesia
Email:
soni.prayogi@universitaspertamina.ac.id

1. Introduction

The shipping industry is one of the main sectors that influences greenhouse gas emissions globally [1]. In this context, CO_2 (*carbon dioxide*), [2] and SO_2 (*sulfur dioxide*) exhaust emissions from tankers are an important concern because of their impact on the marine and air environment [3]. These gas emissions can contribute to global climate change and air pollution which endangers human health and ecosystems [4]. Therefore, monitoring and controlling exhaust gas emissions on tankers is crucial in efforts to maintain environmental sustainability and comply with international regulations related to environmental protection [5].

In recent years, the use of *Internet of Things* (IoT) technology has grown rapidly in various industrial sectors [6], including shipping [7]. The combination of IoT with a PLC (*Programmable Logic Controller*) controller opens up new opportunities in monitoring and controlling exhaust emissions on tankers [8]. PLC controllers can efficiently integrate monitoring systems and provide fast responses to data obtained from sensors installed on ships [9]. By utilizing Internet connectivity, the collected data can be accessed in real-time remotely [10], enabling engineers and ship operators to carry out analysis and corrective action more quickly and effectively [11].

Although there have been previous efforts to reduce exhaust emissions on ships, further research is still needed to improve the efficiency and effectiveness of monitoring and control systems [12]. There are technical challenges in integrating an IoT-based PLC controller system with existing ship infrastructure and ensuring its operational reliability and safety in harsh maritime environments [13]. In addition, regulatory aspects and compliance with environmental standards also need to be considered in the development of these new solutions [14]. Therefore, this research aims to investigate the potential for using IoT-based PLC controllers in monitoring and controlling CO_2 and SO_2 exhaust emissions on tankers, taking into account relevant technical [15], environmental [16], and regulatory aspects [17]. It is hoped that the results of this research can make a significant contribution to efforts to maintain environmental sustainability and develop environmentally friendly technology in the shipping industry.

2. Method

This research adopts an experimental approach to investigate the use of IoT-based PLC controllers in monitoring and controlling CO_2 and SO_2 exhaust emissions on tankers. First of all, planning and technical preparations are carried out for field testing. Figure 1 shows the block diagram of the system being built. The system developed consists of three main parts, namely a PLC-based machine condition monitoring system, a Raspberry Pi-based data recording system, and a warning system. This involves selecting the tanker that will be used as the research object, as well as identifying and installing the gas sensors needed to measure CO_2 and SO_2 emissions [18]. The sensors will be connected to the PLC controller system via a wired or wireless connection, depending on the configuration chosen. In addition, the IoT network infrastructure will also be prepared to enable real-time data collection and sending information to a centralized monitoring platform.

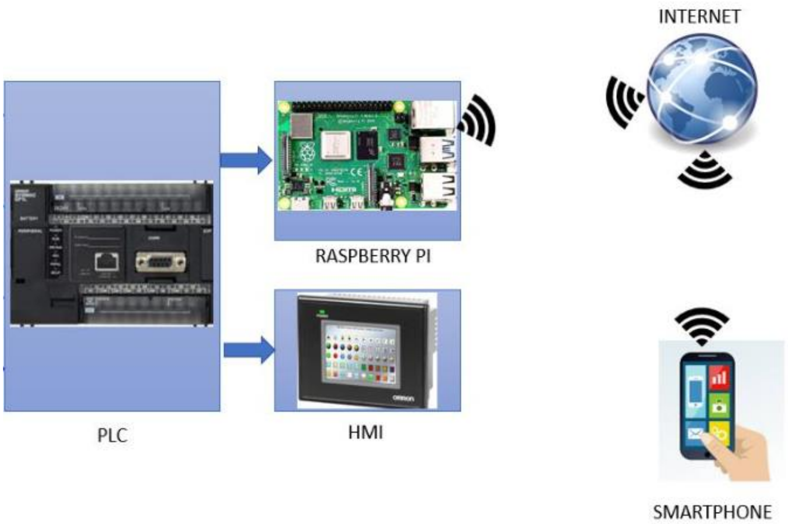

Figure 1. Block diagram of the system being built

Next, field testing was carried out to evaluate the performance of the system in monitoring and controlling exhaust gas emissions on tankers. Testing will be carried out under a variety of operational conditions representative of real situations at sea, including varying speeds and engine loads. Data collected during testing will be analyzed quantitatively to evaluate the level of accuracy and reliability of the system in detecting and measuring CO_2 and SO_2 emissions [19]. In addition, the system's response to changes in operational conditions and the effectiveness of control over gas emissions will be evaluated to determine the effectiveness of the proposed solution [20]. Test results will be used to evaluate system performance and identify potential improvements or improvements that can be made for further development.

3. Result and Discussion

Field testing of the CO_2 and SO_2 exhaust emissions monitoring system on tankers with an IoT-based PLC controller produced very valuable data for further analysis. The measurement results show that the system developed is capable of detecting and measuring CO_2 and SO_2 emission concentrations accurately in various ship operational conditions. Data obtained from the gas sensor shows variations in emissions based on engine speed and load. At low speeds and light loads, CO_2 and SO_2 emissions are relatively low, but increase significantly as engine speed and load increase. This pattern is consistent with theoretical predictions of exhaust emissions, which increase with increasing fuel consumption and engine activity.

Figure 2. Internal components of a switch cabinet installed on a container ship

The effectiveness of the control system in reducing gas emissions was also tested extensively. The IoT-based PLC controller implemented in this system exhibits high adaptive capabilities, responding to gas emission data in real time to optimize engine and exhaust system operations as seen in Figure 2. Through a specially designed control algorithm, the system can adjust engine operating parameters to reduce gas emissions [21]. In this test, the system succeeded in reducing CO_2 and SO_2 emissions by up to 20-30% under certain operational conditions compared to conditions without a controller [22]. This shows that the integration of a PLC controller with IoT not only improves monitoring but also effectiveness in controlling exhaust emissions.

In addition to technical effectiveness, practical aspects of the implementation of this system are also analyzed. One of the main challenges faced is the integration of gas sensors and PLC controllers with existing ship infrastructure. Gas sensors must be placed in strategic locations to obtain accurate data without disrupting ship operations [23]. Additionally, IoT connectivity must be stable to ensure data can be transmitted and analyzed in real time [24]. Testing shows that with proper planning and placement, these challenges can be overcome, although they require adjustments to some components of the ship's infrastructure as seen in Fig. 3. The system's reliability in various maritime environmental conditions was also tested, showing that it can withstand harsh conditions such as high humidity, vibration, and extreme temperatures.

Figure 3. Container ship with approximate location of installed SO2 sensors

p-ISSN: 2963-8577
e-ISSN: 2964-3511

From an environmental and regulatory perspective, the results of this research are very relevant. The developed monitoring and control system meets emission standards set by various international maritime regulatory bodies, such as the *International Maritime Organization* (IMO). By reducing CO_2 and SO_2 emissions, this system not only helps shipping companies comply with environmental regulations but also contributes to global efforts to reduce air pollution and the impact of climate change. In addition, the application of this technology can provide economic incentives for shipping companies through fuel savings and the potential to reduce long-term operational costs [25]. Overall, this research proves that IoT-based PLC controllers are an effective and efficient solution for monitoring and controlling exhaust emissions on tankers, paving the way for further innovation in sustainable maritime technology.

4. Conclusion

In summary, this research has proven that the CO_2 and SO_2 exhaust emissions monitoring system on tankers using an IoT-based PLC controller is an effective and efficient solution. This system successfully detects and measures gas emission concentrations with high accuracy in various ship operational conditions, and shows significant adaptive capabilities through real-time control to reduce gas emissions. Test results show a reduction in CO_2 and SO_2 emissions of up to 20-30%, which not only helps shipping companies comply with international environmental regulations, but also contributes to global efforts to reduce air pollution and the impact of climate change. Technical challenges, such as sensor integration and ship infrastructure, as well as system reliability in harsh maritime conditions, can be overcome with proper planning and adjustments. In addition to providing environmental benefits, these systems also offer the potential for economic savings through reduced fuel consumption and long-term operational costs. Overall, this research paves the way for further developments in sustainable maritime technology, supporting the shipping industry to become more environmentally friendly and efficient.

Acknowledgment

The author would like to thank Pertamina University for the support and facilities provided.

References

[1] L. Zheng, Ed., “Copyright,” in *Oxy-Fuel Combustion for Power Generation and Carbon Dioxide (CO2) Capture*, in Woodhead Publishing Series in Energy. , Woodhead Publishing, 2011, p. iv. doi: 10.1016/B978-1-84569-671-9.50017-X.

[2] S. Ghufron and S. Prayogi, “Cooling System in Machine Operation at Gas Engine Power Plant at PT Multidaya Prima Elektrindo,” *Journal of Artificial Intelligence and Digital Business (RIGGS)*, vol. 1, no. 2, Art. no. 2, 2023, doi: 10.31004/riggs.v1i2.21.

[3] K. El Sheikh *et al.*, “Advances in reduction of NOx and N2O1 emission formation in an oxy-fired fluidized bed boiler,” *Chinese Journal of Chemical Engineering*, vol. 27, no. 2, pp. 426–443, Feb. 2019, doi: 10.1016/j.cjche.2018.06.033.

[4] B. Jin, H. Zhao, C. Zou, and C. Zheng, “Comprehensive investigation of process characteristics for oxy-steam combustion power plants,” *Energy Conversion and Management*, vol. 99, pp. 92–101, Jul. 2015, doi: 10.1016/j.enconman.2015.04.031.

[5] M. Muhammad, B. Ragadita, S. Prayogi, and S. Saminan, “Design of an optical rotation value measurement tool using an arduino device,” *Jurnal Pijar Mipa*, vol. 18, no. 5, Art. no. 5, Sep. 2023, doi: 10.29303/jpm.v18i5.4811.

[6] F. Hu *et al.*, “Evaluation, development, and application of a new skeletal mechanism for fuel-NO formation under air and oxy-fuel combustion,” *Fuel Processing Technology*, vol. 199, p. 106256, Mar. 2020, doi: 10.1016/j.fuproc.2019.106256.

[7] R. A. Ramadhan, G. R. Kakke, I. N. Fajar, and S. Prayogi, “Smart Trash Bin Berbasis Internet Of Things Menggunakan Suplai dari Panel Surya,” *G-Tech: Jurnal Teknologi Terapan*, vol. 7, no. 3, pp. 1149–1158, Jul. 2023, doi: 10.33379/gtech.v7i3.2777.

[8] X. Liang *et al.*, “Experimental and numerical investigation on sulfur transformation in pressurized oxy-fuel combustion of pulverized coal,” *Applied Energy*, vol. 253, p. 113542, Nov. 2019, doi: 10.1016/j.apenergy.2019.113542.

[9] X. Hu, X. Li, G. Luo, and H. Yao, “Homogeneous and heterogeneous contributions of CO2 and recycled NO to NO emission difference between air and oxy-coal combustion,” *Fuel*, vol. 163, pp. 1–7, Jan. 2016, doi: 10.1016/j.fuel.2015.09.030.

[10] S. Li, Y. Xu, and Q. Gao, “Measurements and modelling of oxy-fuel coal combustion,” *Proceedings of the Combustion Institute*, vol. 37, no. 3, pp. 2643–2661, Jan. 2019, doi: 10.1016/j.proci.2018.08.054.

[11] A. P. M. Erlangga, K. S. K. Dinatha, F. E. Nainggolan, and S. Prayogi, "Prototipe Otomatisasi dan Pemantauan Sistem Hidroponik Berbasis IoT dengan Pemanfaatan Solar Panel Sebagai Sumber Energi," *G-Tech: Jurnal Teknologi Terapan*, vol. 7, no. 4, pp. 1367–1377, Oct. 2023, doi: 10.33379/gtech.v7i4.3143.

[12] M. de las Obras-Loscertales *et al.*, "NO and N2O emissions in oxy-fuel combustion of coal in a bubbling fluidized bed combustor," *Fuel*, vol. 150, pp. 146–153, Jun. 2015, doi: 10.1016/j.fuel.2015.02.023.

[13] Q. Liu, W. Zhong, and A. Yu, "Oxy-fuel combustion behaviors in a fluidized bed: A combined experimental and numerical study," *Powder Technology*, vol. 349, pp. 40–51, May 2019, doi: 10.1016/j.powtec.2019.03.035.

[14] L. Chen, S. Z. Yong, and A. F. Ghoniem, "Oxy-fuel combustion of pulverized coal: Characterization, fundamentals, stabilization and CFD modeling," *Progress in Energy and Combustion Science*, vol. 38, no. 2, pp. 156–214, Apr. 2012, doi: 10.1016/j.pecs.2011.09.003.

[15] H. Zebian and A. Mitsos, "Pressurized OCC (oxy-coal combustion) process ideally flexible to the thermal load," *Energy*, vol. 73, pp. 416–429, Aug. 2014, doi: 10.1016/j.energy.2014.06.031.

[16] G. Coraggio, L. Tognotti, D. Cumbo, N. Rossi, and J. Brunetti, "Retrofitting oxy-fuel technology in a semi-industrial plant: Flame characteristics and NO*x* production from a low NO*x* burner fed with natural gas," *Proceedings of the Combustion Institute*, vol. 33, no. 2, pp. 3423–3430, Jan. 2011, doi: 10.1016/j.proci.2010.07.024.

[17] S. Li, W. Li, M. Xu, X. Wang, H. Li, and Q. Lu, "The experimental study on nitrogen oxides and SO2 emission for oxy-fuel circulation fluidized bed combustion with high oxygen concentration," *Fuel*, vol. 146, pp. 81–87, Apr. 2015, doi: 10.1016/j.fuel.2014.12.089.

[18] F. Silviana and S. Prayogi, "Utilization of Smartphones in Experiments of Measurement of Electron-Mass Charge Ratio," *International Journal of Engineering and Science Applications*, vol. 10, no. 1, Art. no. 1, May 2023.

[19] F. Silviana and S. Prayogi, "An Easy-to-Use Magnetic Dynamometer for Teaching Newton's Third Law," *Jurnal Pendidikan Fisika dan Teknologi*, vol. 9, no. 1, Art. no. 1, Jun. 2023, doi: 10.29303/jpft.v9i1.4810.

[20] M. Marzuki, S. Prayogi, and M. Abdillah, "Data-Driven Based Model For Predictive Maintenance Applications In Industrial System," presented at the Proceedings of the International Conference on Sustainable Engineering, Infrastructure and Development, ICO-SEID 2022, 23-24 November 2022, Jakarta, Indonesia, Dec. 2023. Accessed: Jun. 04, 2024. [Online]. Available: https://eudl.eu/doi/10.4108/eai.23-11-2022.2341596

[21] S. Prayogi, Y. Cahyono, I. Iqballudin, M. Stchakovsky, and D. Darminto, "The effect of adding an active layer to the structure of a-Si: H solar cells on the efficiency using RF-PECVD," *J Mater Sci: Mater Electron*, vol. 32, no. 6, pp. 7609–7618, Mar. 2021, doi: 10.1007/s10854-021-05477-6.

[22] S. Prayogi, A. Ayunis, Y. Cahyono, and D. Darminto, "N-type H2-doped amorphous silicon layer for solar-cell application," *Mater Renew Sustain Energy*, Apr. 2023, doi: 10.1007/s40243-023-00232-9.

[23] D. Hamdani, S. Prayogi, Y. Cahyono, G. Yudoyono, and D. Darminto, "The influences of the front work function and intrinsic bilayer (i1, i2) on p-i-n based amorphous silicon solar cell's performances: A numerical study," *Cogent Engineering*, vol. 9, no. 1, p. 2110726, Dec. 2022, doi: 10.1080/23311916.2022.2110726.

[24] S. Prayogi and M. I. Marzuki, "The Effect of Addition of SnO2 Doping on The Electronic Structure of TiO2 Thin Film as Photo-Anode in DSSC Applications," *Journal of Emerging Supply Chain, Clean Energy, and Process Engineering*, vol. 1, no. 1, Art. no. 1, Sep. 2022, doi: 10.57102/jescee.v1i1.3.

[25] Z. Zainuddin, M. Syukri, S. Prayogi, and S. Luthfia, "Implementation of Engineering Everywhere in Physics LKPD Based on STEM Approach to Improve Science Process Skills," *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, vol. 10, no. 2, Art. no. 2, Apr. 2022, doi: 10.24815/jpsi.v10i2.23130.

Biographies of Authors

Iqbal Nur Fajar is a student of the Electrical Engineering Study Program, Faculty of Industrial Engineering, Pertamina University class of 2019. He can be contacted at email: Iqbal89@gmail.com.

Dr. Soni Prayogi, M.Si currently works in Electrical Engineering, at Pertamina University, Indonesia. He does research in materials science, condensed matter physics, magnetic compounds, and nano-/2D-materials. He can be contacted at email: soni.prayogi@ universitaspertamina.ac.id.