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DESIGN OF AUTONOMOUS DISINFECTION SYSTEMS FOR HIGH-TRAFFIC AREAS ON SHIPS

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Abstract
Regular cleaning of damaged ship hulls during dry dock repair ensures the efficient functioning of the shipping sector. Implementing an autonomous mechanism for corrosion removal by water disinfection is a viable strategy to alleviate manual labor demands while minimizing water, time, and energy expenditure. This research proposes a water-disinfection method for a unique robotic platform termed Hornbill, which utilizes an ongoing magnetic attachment mechanism and sensor fusion for self-location to navigate effectively on vertical surfaces. Therefore, the research suggests a Comprehensive Way-point Path Planning (CWPP) to re-disinfect the self-synthesizing Deep Convolutional Neural Networks (DCNN) on the corrosion heatmap through initial disinfection. The ideal CWPP issue, which encompasses minimizing trip length and duration to conserve water and power whilst ensuring all designated waypoints are visited, is formulated as the classical Traveling Salesman Problem (TSP). The Pareto-optimal path for the specified TSP has been derived using Reinforcement Learning (RL) techniques, incorporating a suggested reward system depending on the robot's performance during disinfection operations. The findings from experiments at the shipyard indicate that the suggested RL-based CWPP produces a Pareto-optimal path, allowing the water-disinfection robots to utilize around 12% less energy and 8% less water compared to the second-greatest evolutionary-based optimizing approach across diverse workplaces.
Keywords – Disinfection, Ships, Deep Learning, Cleaning

1. INTRODUCTION

Cruise tourism has gained significant popularity [1]. Infectious epidemics are commonly documented on cruise ships [2]. Traveling on cruise ships exposes individuals to novel locations and substantial populations, heightening the potential of virus transmission. Frequent personal encounters, intricate demographics, constrained space, and inadequate infrastructure on numerous cruise ships render them potential breeders for infectious diseases [3]. Controlling infections on cruise ships is difficult due to communal living and dining areas, high passenger and employee turnover, and multiple avenues for germ introduction onboard [20].

The silky texture of ship hulls deteriorates during operation due to the adhesion of marine particles and surface deterioration—the direct contact of the hull's metallic layer results in the degradation of the paint layer. To maintain sustainability, a ship hull requires repainting every 4-6 years [4]. The rust level must be regularly assessed to determine the safety status of vessels. The current paint and any potential rust coatings must be removed before repainting. Hydro disinfections are typically used on ships' hulls for this objective [21]. High-pressure water is propelled onto ship hulls using heavy machinery handled by human workers. The effectiveness, expense, and security are primary problems of traditional methods for ship hull demolition, which necessitate a substantial human workforce. Robotic researchers have shifted their focus to developing robotic systems for the autonomous hydro disinfection of ship hulls.

Robotic automated servicing and inspection techniques have demonstrated adaptability across multiple sectors, including building upkeep, highway upkeep, and service robots for path tracking [5]. Likewise, numerous robotic methods have been suggested for automating the examination and upkeep tasks performed in a dry dock. The ship servicing sector has benefited from deploying various robotic instruments affixed to terrestrial constructions like cranes. These terrestrial robotic methods exhibit suboptimal performance when accessing an entire ship hull.

Robotic methods utilizing Unmanned Aerial Vehicles (UAVs) have been suggested to enhance access to a ship hull [6]. The current UAV-based systems are restricted to inspections and cannot manage instruments, such as blowing guns, necessary for repairs.

Falling robot systems are extensively employed for the upkeep and examination of rooftops because of their inherent accessibility. Likewise, numerous climbing robots have been designed for the ship servicing sector. The predominant type of these machines is wheeled robots equipped with magnetic attachment, as ship hulls are constructed from magnetic substances. The research is confined to creating equipment designs for climbing, aimed explicitly at ship maintenance [19].

2. RELATED WORKS

Robotics for ship hull repair must be outfitted with systems for surface inspection to facilitate decision-making. Most of these inspection devices employ computer vision to identify corroded regions of hulls. In addition to optical systems, the application of laser-based measurement systems for flaw detection was noted. The study offered background subtraction strategies utilizing histogram analytics [18]. Feed-Forward Neural Networks (NN) (FFNN) and Deep Convolutional NN (DCNN) have been suggested for corrosion detection [7]. Despite the numerous methodologies presented to identify corrosion during ship checks, the existing systems have not advanced to provide a completely integrated solution for ship hull inspection and disinfection. Applying the methods to assess disinfection efficiency is questionable, as the surface aspect will alter due to the natural accumulation of corrosion following the disinfection process [11].

The research presented a comprehensive method capable of detecting corroded regions in a ship hull and executing targeted disinfection on the detected corrosion spots. A manipulator executes the disinfection affixed to a crane [12]. The system's efficiency in assessing the smoothness of a pre-blasted surface has not been addressed within the parameters of this discussion. The research has not addressed establishing paths for energy-efficient covering of disinfection sites [13].

A method for assessing the quality of the disinfection cycle and creating a comparison map for targeted re-disinfection has been suggested [17]. The approach employs a self-organizing fuzzy logic decoder to classify disinfection quality. The project is confined solely to creating a disinfection benchmarking platform. The referenced work does not address the path modeling and variable setup for re-disinfection rounds [14].

The study provided an effective path planning methodology for a spot disinfection device. The suggested method correlates the spot disinfection process with the Traveling Salesman Problem (TSP) and employs Genetic Algorithms (GA), Reinforcement Learning (RL), and movement planning to determine the optimal trajectory [9][15]. The optimization criterion is to identify the shortest route. No on-site trials with the robotic hardware systems have been executed; validation has solely occurred through a rigorously limited simulator. The primary drawback of the study is the presumption that travel length is the exclusive determinant of energy conservation [16]. In contrast, the energy consumption of disinfection robots on a ship hull is influenced by additional factors, including movement orientation (horizontal or vertical), movement, and water use. Time efficiency is a critical consideration in the manufacturing process, which this study has not addressed [10].

3. PROPOSED AUTONOMOUS DISINFECTION SYSTEMS

Fig.1 illustrates an automated system with a customizable manipulator intended for cleaning and self-assessing the ship hull surfaces during dry dock repair. The upkeep of the ship hull was typically conducted through a set of procedures. The research established an autonomous architecture to replicate the hydro disinfection operation. The proposed robot initiates its independent zigzag movement to commence the preliminary removal of painted and rusted layers from the surface. The results illustrate the standard result of a ship's surface following blowing. The machine would traverse an irregular surface throughout the operation, resulting in a greater gap than the suggested distance from the sprayer of the disinfection component and the ground. This results in a force drop during disinfection, leading to dirty surfaces.

Inadequately cleaned surfaces lead to complications during the painting of the vessel's hull, adversely impacting its efficiency at sea by creating additional corroded areas over time. Maintaining a uniform surface cleaning standard during hydraulic disinfection operations is essential.

To clean the vessel's hull surface uniformly, the researchers employed a benchmarking technique to replace the arm's terminal end with an imaging device. The robot executes cleanliness categorization via DCNN from the images recorded during its zigzag movement. Upon completion of the covering, a benchmarking image was produced, illustrating its exterior purity. The image resembles a heat map, where more heat (strength of red) indicates diminished cleanliness. Utilizing the created heat map, the machine will formulate an appropriate trajectory for re-disinfection in the uncleaned region, prioritizing the shortest navigational separation, minimal vertical ascent, and reduced water and energy use. During the re-disinfection procedure, the robot will adjust the water pressures (selected pressure Pa) based on the level of surface cleaning in the chosen region. These techniques enhance the efficacy of autonomous ship hull blowing and inspection operations.

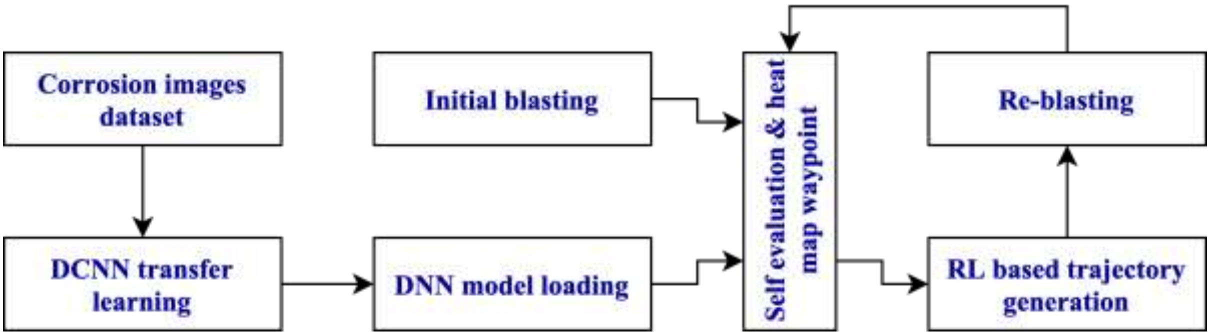

Fig. 1. Closed-loop optimal water disinfection

4. RESULTS AND FINDINGS

The intervention research examined the effects of diverse infection-control methods on multiple outcomes.

4.1 Measures

The study consisted of four arms. Initial information was gathered in the initial arm. Each successive arm incorporated an additional facet of infection control protocols.

4.2 Surface decontamination

High-contact surfaces play a crucial role in the spread of infections. Antibacterial sprays are promoted as solutions that can render surfaces perpetually self-disinfecting. This would represent a significant advancement in infection management, as these surfaces that clean themselves would disrupt the transmission chain of infections.

Two commercially available antibacterial treatment aerosols were chosen. The goods' names will remain undisclosed to safeguard the producers' business interests. The active constituents of these sprays were two distinct quaternary ammonia substances. Spray #A asserts an 85% reduction in Colony-Forming Units (CFU) relative to traditional cleaning methods, maintained for up to 65 days. Spray #B can eliminate 98% of germs and keep surfaces free from bacteria for up to 35 days. The two sprays were administered on multiple high-contact surfaces of the ship: the two primary staircases, all interior railings, and toilet knobs on Decks 4, 6, and 7. All exterior and interior elevator screens were serviced for the six primary staircases.

4.3 Behavioral modification induced by technologies

The Semmelweis Hand Cleaning Scanner was implemented on the vessel as a novel solution to illustrate hand coverage following hand hygiene practices. The device utilizes a fluorescence-based approach, a prevalent tool for evaluating hand hygiene efficacy. The handrub includes a fluorescent indicator. Following hand sterilization, areas that have been adequately treated emit a glow under UV light, whilst unclean regions remain devoid of illumination. The Semmelweis Technology identifies these concealed (and ostensibly cleaned) regions and delivers prompt, impartial evaluations regarding hand hygiene efficacy.

The initial version of this figure contained photographic elements that have been eliminated to adhere to preprint regulations forbidding identifying pictures. Individuals seeking access to the original visualizations should contact the appropriate author for additional details.

Crew members received QR codes for system identification purposes. The QR barcodes were allocated arbitrarily. Involvement was optional for all crew participants; only a subset of the crew engaged in the study. Visitors were additionally provided the option to use the gadget without an identity.

4.4 Training on Hand Hygiene

Crew members participated in pairs of roughly 16 individuals apiece. The workout sessions lasted for a duration of 21 to 30 minutes. Throughout the three days, an aggregate of 370 staff members engaged. The crew was requested to answer questions on a survey evaluating their expertise and mindsets before and during the training, to measure knowledge enhancement. After the training, the most recent iteration of the training content was documented as an animation for future reference. The clip was edited with Microsoft PowerPoint. It is accessible in countries other than English. Translating was supplied via ChatGPT, and the material was vocalized using NaturalReaders.

Travelers were provided with a pamphlet highlighting the significance of hand hygiene during the flight. The brochure was disseminated as a pillow note in guest rooms upon entrance. It emphasized cruise-specific instances for proper hand washing and encouraged guests to utilize the Semmelweis Method to assess their hand hygiene performance at all times.

5. RESULTS

5.1 Dataset Preparation

The dataset is obtained by employing the robot to document the corroded regions of an actual ship hull before and after disinfection. The expert annotates the gathered photographs. Twenty-five thousand photos are allocated, 80 percent designated for teaching and 25 percent for validation.

5.2 Measuring and heatmap development for the initially disinfection surface of water

The research executes the suggested benchmarks and histogram generation on the actual ship hull experimentation. The disinfection robots had earlier subjected the ship hull to a pressure of 2600 Bar. It has the Hornbill robot equipped with the comparison component, which traverses a zigzag trajectory to execute the measurement function. Upon loading the learned DCNN approach, the robot categorizes the input pictures into RGB while executing the zigzag movement function. The testing device can achieve continuous operations at 20 frames per second. The odometry information is obtained from the fusion system of UWB-based devices. The robot width is determined to be 0.79 m. The method generates a heatmap for all workplace regions by picking a picture frame at every 0.77 m interval.

The comparison histogram for the robot-operated region is derived by generating the probability outputs of every frame of imagery from the DCNN. The research was conducted in two distinct workplaces. The grid-based workstation features a cell size equivalent to the dimension of the robot Ir. The likelihood of surface degradation levels for each grid cell is obtained from the DCNN result and recorded in the generated heatmap. The cells with lower probabilities indicate the more pristine locations. The results exhibit certain unrefined regions and display elevated likelihood values attributable to the original hydro disinfection inaccuracies. The research conducts experiments using an expanded cleaning workstation and 10 × 10 heat maps, where dirty regions exhibit elevated probability values. The suggested DCNN system demonstrates effective classification and performance in real-time.

The results depict temperature maps of 10 x 10 workplaces exhibiting varying corrosion stages: moderate, light, and severe. It displays each heatmap and its corresponding cell probability. The research first employed 2600 bars to eliminate the examined corroded surfaces. However, sanitation performance is inconsistent due to the nozzle diameter and length of the plate. The resultant heatmap of the mild corrosion level workspace reveals a predominance of lower-probability tissues, with a limited presence of greater corrosion cells. Conversely, an area with a high level of corrosion produces smaller likelihood units.

The research observes some misclassifications while using the algorithm in real time. The suggested classification achieves approximately 95% mean efficiency. Given that the benchmarking method depends on the robot's status, it is imperative to uphold the dependability and accuracy of combining sensors for robot location throughout navigation to minimize errors in the production of the measuring hotspot. The resultant heatmap verifies that each initial disinfection-specified environment quality adheres to industrial standards before applying the new painted layer. The coarse surface of the ship's deck can compromise the quality of repair efforts. Creating a hotspot for the initial disinfection area enabled targeted spot disinfection in locations that failed to reach the required standards. The location of the contaminated area, shown by the hotspot, would be advantageous in devising an effective re-disinfection strategy.

The research can determine the required strength for the re-disinfection procedure by depicting the disinfection quality classes on the map. The medium stress number is utilized for regions classified within the medium-high comparison category. The research will exert more pressure if the area classification is deemed inadequate. The research designates a chance of 0.7 for detecting the cell to advance to the subsequent phase of planning the design for the re-disinfection operation. The results depict the defined thermal maps for the 6 x 6 and 12 x 12 medium corrosion level workplaces. It shows the defined temperature maps of the 12 × 12 workstations for mild to moderate corrosion levels. The suggested automated device is viable for performing hydro disinfection and evaluation by continuously adapting an appropriate manipulation. It generates benchmarking heat maps for an already disinfected region.

6. CONCLUSION

The RL-based optimal strategy for the Hornbill robotic will enhance disinfection performance and provide effective selected re-disinfection before applying new paint coatings. The suggested autonomous corrosive cleaning method has been verified in simulated and actual situations. A proposed ideal CWPP function for robotic operations encompasses minimizing trip distance and upward movement to conserve water and energy, while guaranteeing all designated uncleaned waypoints are visited. The optimum planning of paths has been contrasted with conventional approaches such as zigzag, spiral, and greedy searching.

This preliminary endeavor is to implement the autonomous system for cleaning the ship deck by water disinfection at Keppel Shipyard. The proposed technology could improve traditional hydro disinfection operations in the ship hull repair sector. The suggested automated water-disinfection system comprehensively cleans the ship hull while prioritizing environmental and human safety in ship upkeep.

While the proposed technology has been proven on the actual vessel surface in the shipyard, it now operates within a relatively limited area. The researchers are building a system to operate independently in an intricate setting with clustered barrier configurations. Upon the next version platform's adherence to ship service norms, the ideal CWPP variable configuration will be determined to enable the suggested robot to function independently over an extended period. Future studies concentrate on the correlation between robotic kinematic layout and surface contact, the spatial distribution of magnetic forces as a consequence of TSP, the role of friction in navigating tactics, and the creation of RL-based heatmaps under varying lighting circumstances.

REFERENCES

1. Smirnov, A., Smolokurov, E., Timofeeva, E., & Krovsh, S. (2022). Features of development of sea cruise tourism. Transportation Research Procedia, 61, 147-154.
2. Soy, A., & Balkrishna, S. M. (2024). Automated detection of aquatic animals using deep learning techniques. International Journal of Aquatic Research and Environmental Studies, 4(S1), 1-6. https://doi.org/10.70102/IJARES/V4S1/1
3. Mukherjee, S., Kulshreshtha, M., Pancholi, B., & Garabadu, D. (2024). Impact assessment of virus globally: special emphasis on COVID-19, Zika, and Ebola virus. In Nanostructured Drug Delivery Systems in Infectious Disease Treatment (pp. 25-63). Academic Press.
4. Saritha, R. R., & Gunasundari, R. (2024). Enhanced Transformer-based Deep Kernel Fused Self Attention Model for Lung Nodule Segmentation and Classification. Archives for Technical Sciences, 2(31), 175–191. https://doi.org/10.70102/afts.2024.1631.175
5. Tian, Y., Chen, C., Sagoe-Crentsil, K., Zhang, J., & Duan, W. (2022). Intelligent robotic systems for structural health monitoring: Applications and future trends. Automation in construction, 139, 104273.

6. Bansal, M., & Naidu, D. (2024). Dynamic Simulation of Reactive Separation Processes Using Hybrid Modeling Approaches. Engineering Perspectives in Filtration and Separation, 2(2), 8-11.
7. Allah, M. A. A., Toor, I. U., Shams, A., & Siddiqui, O. K. (2025). Application of machine learning and deep learning techniques for corrosion and cracks detection in nuclear power plants: A review. Arabian Journal for Science and Engineering, 50(5), 3017-3045.
8. Mendes, C., & Petrova, O. (2024). Terminology Mapping in Health Information Exchanges: A Case Study on ICD and LOINC Integration. Global Journal of Medical Terminology Research and Informatics, 2(2), 18-21.
9. Li, H., Meng, S., & Tong, H. (2021). How to control cruise ship disease risk? Inspiration from the research literature. Marine Policy, 132, 104652.
10. Rathi, S., Mirajkar, O., Shukla, S., Deshmukh, L., & Dangare, L. (2024). Advancing Crack Detection Using Deep Learning Solutions for Automated Inspection of Metallic Surfaces. Indian Journal of Information Sources and Services, 14(1), 93–100. https://doi.org/10.51983/ijiss-2024.14.1.4003
11. Ghazali, M. H. M., Satar, M. H. A., & Rahiman, W. (2024). Unmanned surface vehicles: From a hull design perspective. Ocean Engineering, 312, 118977.
12. Mitra, A., & Shah, K. (2024). Bridging the Digital Divide: Affordable Connectivity for Quality Education in Rural Communities. International Journal of SDG's Prospects and Breakthroughs, 2(1), 10-12.
13. Oliveira, D. R., Lagerström, M., Granhag, L., Werner, S., Larsson, A. I., & Ytreberg, E. (2022). A novel tool for cost and emission reduction related to ship underwater hull maintenance. Journal of Cleaner Production, 356, 131882.
14. Aburasain, R. Y. (2025). Revolutionizing Traffic Flow Prediction Using a Hybrid Deep Learning Models with Kookaburra Optimization Algorithm. Journal of Internet Services and Information Security, 15(1), 486-501. https://doi.org/10.58346/JISIS.2025.I1.032
15. Hernández-García, S., Cuesta-Infante, A., Moreno-SanSegundo, J. Á., & Montemayor, A. S. (2023). Deep reinforcement learning for automated search of model parameters: photo-fenton wastewater disinfection case study. Neural Computing and Applications, 35(2), 1379-1394.
16. Hu, X., & Sinniah, S. (2024). The Role of Green Risk Management Approaches in Promoting Green and Sustainable Supply Chain Management. Natural and Engineering Sciences, 9(2), 33-54. https://doi.org/10.28978/nesciences.1569144
17. Veerasamy, K., & Fredrik, E. J. T. (2023). Intelligence System towards Identify Weeds in Crops and Vegetables Plantation Using Image Processing and Deep Learning Techniques. Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 14(4), 45-59. https://doi.org/10.58346/JOWUA.2023.I4.004
18. Kumari, D., & Hussain, T. (2024). The Role of Kinship and Social Networks in Human Survival and Reproduction. Progression Journal of Human Demography and Anthropology, 2(3), 5-8.
19. Yeo, M., & Jiang, L. (2024). Thermal and Fluid Systems: Analysis, Design, and Optimization. Association Journal of Interdisciplinary Technics in Engineering Mechanics, 2(1), 7-12.
20. Trisiana, A. (2024). A Sustainability-Driven Innovation and Management Policies through Technological Disruptions: Navigating Uncertainty in the Digital Era. Global Perspectives in Management, 2(1), 22-32.
21. Bhupesh, B., Dharun, D., Dhurgadevi, D., Gopalakrishnan, G., & Nagarajan, N. (2023). Image Encryption and Decryption using RSA Algorithm in Deep Learning. International Journal of Advances in Engineering and Emerging Technology, 14(1), 69–76.
22. Tang, L., Chen, Y., & Zhou, J. (2025). Reconfigurable computing architectures for edge computing applications. SCCTS Transactions on Reconfigurable Computing, 2(1), 1–9. https://doi.org/10.31838/RCC/02.01.01
23. Alaswad, H., & Hooman, K. (2025). Thermal management in electronics using advanced technologies for heat transfer. Innovative Reviews in Engineering and Science, 3(1), 19–25. https://doi.org/10.31838/INES/03.01.03
24. Vijay, V., Pittala, C. S., Usha Rani, A., Shaik, S., Saranya, M. V., Vinod Kumar, B., Praveen Kumar, R. E. S., & Vallabhuni, R. R. (2022). Implementation of Fundamental Modules Using Quantum Dot Cellular Automata. Journal of VLSI Circuits and Systems, 4(1), 12–19. https://doi.org/10.31838/jvcs/04.01.03
25. Abdullah, D. (2025). Nonlinear dynamic modeling and vibration analysis of smart composite structures using multiscale techniques. Journal of Applied Mathematical Models in Engineering, 1(1), 9–16.
26. Andrade, F. (2024). The Role of Total Quality Management: SME. National Journal of Quality, Innovation, and Business Excellence, 1(1), 30-36.

27. Carlos, A. H., & Rojas, M. D. (2024). The Impact of Tourist Expectations on Cultural Authenticity in Urban Tourism. Journal of Tourism, Culture, and Management Studies, 1(2), 9-16.
28. Rahmanto, E., Ardiana, K. R., & Dewa, I. (2025). The Influence of Perceptions of Organizational Support, Knowledge Management and Transformational Leadership on Employee Psychology Empowerment and Organizational Citizenship Behavior and Its Impact on Innovative Work Behavior. Quality-Access to Success, 26(206).