

Robotic Solutions for Air Duct Cleaning: An Overview of Current Research and Applications

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Abstract - According to studies conducted abroad, the HVAC system is to blame for 70% or more of all IAQ problems, and most of these problems are brought on by inadequate system care and maintenance. The lungs of a building, the air ducts, can accumulate deposits of construction grime, dust, tar from cigarettes, insects, smoke and other airborne contaminants. These distribution systems need to be inspected frequently in order to maintain the high efficiency of the air conditioners and lower effect losses. There is evidence that ventilation ducts in HVAC systems can accumulate dust and serve as breeding grounds for microbes even when they are operating normally. The building's AC duct placement makes it impossible to clean by hand. An assessment of the current state of knowledge and comprehension about the employment of robots for air duct cleaning is what this review paper intends to do. The various varieties of air duct cleaning robots, as well as their capabilities and effectiveness in comparison to more conventional cleaning techniques, will be examined in this study. The cost, effectiveness, and safety of deploying robots to clean air ducts will also be discussed in this study, along with some of their benefits and drawbacks. The review will also look at the state of research and development in the area and identify any potential trends or difficulties in the use of robots for cleaning air ducts in the future. The paper will include a full evaluation of previous research on the subject, including studies, publications, and reports, as well as the methodology employed. The study will include findings and suggestions about the usage of robots for cleaning air ducts for facility managers, researchers, and air duct cleaning specialists. The paper's overall goal is to present a thorough overview of the status of technology today and some of its prospective air duct cleaning applications.

Keywords: HVAC, Duct Cleaning, Robotics, IAQ

I. INTRODUCTION

Cleaning the HVAC system of a building's ductwork involves removing debris, dust, and other impurities. It is necessary because, over time, these impurities may accumulate in the ducts, lowering the HVAC system's effectiveness and harming the interior air quality.

The need for duct cleaning has numerous justifications. One explanation is that the accumulation of impurities in the ducts may obstruct airflow and increase the HVAC system's workload, making it more difficult to distribute air throughout the building. Higher energy costs and a shorter

equipment lifespan may result from this. Furthermore, the contaminants may be home to mould, bacteria, and other microorganisms that could be harmful to building occupants' health. According to research cited by the author, "Our daily work practises introduce several pollutants into our interior environments, including dust, mites, mould, bacteria, pollen, smoking, and nicotine, all of which promote the growth and spread of bacteria and mould", [1]. Cleaning the ducts can help enhance the quality of the air in general by removing allergies, dust, and other contaminants.

The building's safety is another justification for duct cleaning. Fire risks might result from the build-up of debris in the ducts [2]. Particularly in the dryer vent, dust and lint can build up and pose a risk of fire. In order to preserve the effectiveness and safety of a building's HVAC system and enhance interior air quality, duct cleaning is a crucial maintenance task that should be carried out on a regular basis.

A review of air duct cleaning would give a general overview of what is currently known and understood about the subject. This might cover details on the advantages of air duct cleaning, the procedures used to clean them, and any potential health or safety risks. The effectiveness of various air duct cleaning techniques as well as the influence of duct cleaning on indoor air quality might be examined in the review. The review may also consider any rules or guidelines that apply to the cleaning of air ducts as well as the training requirements for duct cleaners. Additionally, this review's objectives include highlighting any gaps in the state of the field's knowledge and research, recommending topics for additional investigation, and giving an overview of recent findings.

The review could focus on the various robot types utilised for air duct cleaning, their features, and how well they perform when compared to more conventional cleaning techniques. Using robots to clean air ducts has both benefits and drawbacks, including costs, effectiveness, and safety, which might be examined in the review. The review could also determine any potential trends or difficulties in the use of robots for air duct cleaning in the future. It could also evaluate the state of research and development in the area.

The overall goal of the review on using robots for air duct cleaning is to give a thorough assessment of the state of technology today, its possible uses, and any drawbacks or difficulties that might arise from using it for air duct cleaning.

II. LITERATURE SURVEY

Epsco Envirotech [1] HVAC cleaning services are provided by this company. For most environments to guarantee a pleasant, cosy, and secure working environment, heating, ventilation, and air conditioning (HVAC) are crucial. This system is comparable to our respiratory system. It circulates the air once it takes it in to make sure the particles reach every nook and cranny of the interior space. The worst part, though, is that it repeatedly blows the same air throughout the day. Because of our way of life, the indoor environment is contaminated with dust, mites, mould, bacteria, pollen, smoke, tobacco, and pet hair. Additionally, they all permitted the growth and spread of bacteria and mould in our indoor living space. These impurities degrade the lifespan of the cooling and heating systems by making them work harder. Because of this, 25% to 40% of the energy used for heating or cooling is lost. An HVAC system works more efficiently to maintain the temperature you want when it is clean. As a result, less energy is used, improving cost effectiveness.

Nirmitee Robotics [2], The World Health Organisation (WHO) estimates that in only the year 2000, indoor air pollution caused approximately 1.5 million fatalities and 2.7% of all disease-related deaths worldwide. Allergies, infectious diseases, and respiratory illnesses are all considerably accelerated by the negative impacts of dirty and filthy HVAC air ducts in homes and offices. The lifespan of

the system is shortened, and an early replacement is required if the collected dust and pollutants in HVAC air ducts are not cleaned over time. To increase the useful life of your expensive HVAC system, regular air duct cleaning is necessary. When ducts are dirty and clogged, the machinery is put under more stress, which decreases productivity and hastens component wear and tear. As a result, your HVAC system's operational and maintenance expenses rise dramatically, leading to higher water and electricity bills, a more frequent need for spare component replacement, and occasionally even the need to replace the entire system. Financial costs that go beyond the initial outlay can result from improper air duct cleaning.

Priya Dhengre *et al.*, [3] The research presented in "Air Duct Cleaning Robot" by Priya Dhengre, Aditi Lambade, Vaidehi Maske, Neha Gajway, Karishma Dhone, and Amit Kale, published in the International Research Journal of Engineering and Technology (IRJET) in March 2020, focuses on the design and development of a robot specifically made for cleaning rectangular AC ducts. The authors suggest an all-encompassing system made up of a monitor and control device, a remote robot, and a dust collection tool. They emphasise how crucial it is to navigate the ducts well, which is accomplished by using a guiding system that guarantees straight paths and automatically turns at curves. The robot uses the NRF module to operate, and it has a four-wheeled system for seamless mobility and enhanced grasping. The authors also add a powered individual IP camera for defect and leakage detection. The Arduino UNO is in charge of the system's wireless control and coding. Overall, the study offers insightful technical information on the development of an air duct cleaning robot.



Fig. 1 Air Duct Cleaning Robot [3]

Aditya Pratap Singh *et al.*, [4], The research paper "Duct Inspection and Cleaning Robot" by Aditya Pratap Singh, Jitin Malhotra, Nikita Gupta, Pratik Jaiswal, Adiba Kausar, and Mohit Bhandwal, which was released in the International Journal of Mechanical and Production Engineering in February 2016, focuses on the creation of a robot intended for inspecting and cleaning ducts. The authors discuss the significance of maintaining clean ducts in various sectors and suggest a thorough system to handle this work. For efficient duct cleaning and navigation, the robot is outfitted with

inspection cameras and cleaning equipment. The writers underline the necessity for an automated solution as they talk about the difficulties involved with duct inspection and cleaning. The robot's capacity to navigate various duct forms and their presentation of the robot's concept and implementation are highlighted. The study contributes to the subject of industrial maintenance and hygiene by offering insightful information on the creation of a duct inspection and cleaning robot.

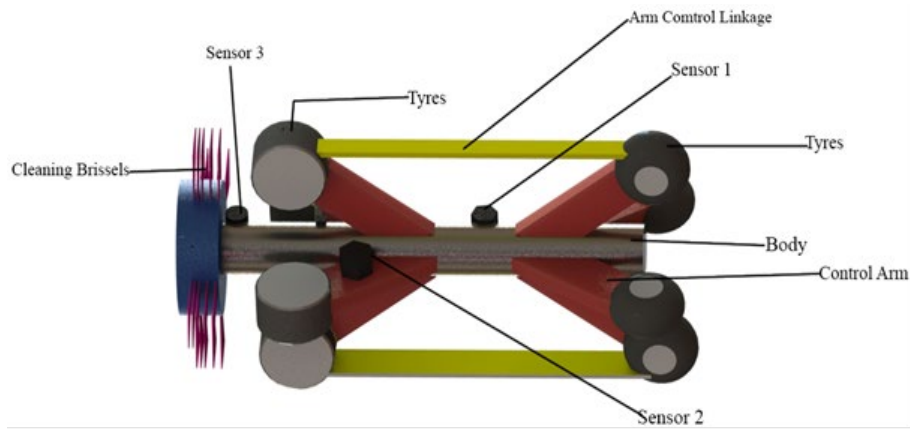


Fig. 2 Duct Inspection and Cleaning Robot [4]

By using this robot with cleaning brushes to clear the ducts of dust, bacteria, and fungi, they were able to accomplish some significant results. The dust concentrations in this

experiment have been measured in gm/m². The use of it with various types of ducts has resulted in the biggest improvement, or 98.22%.

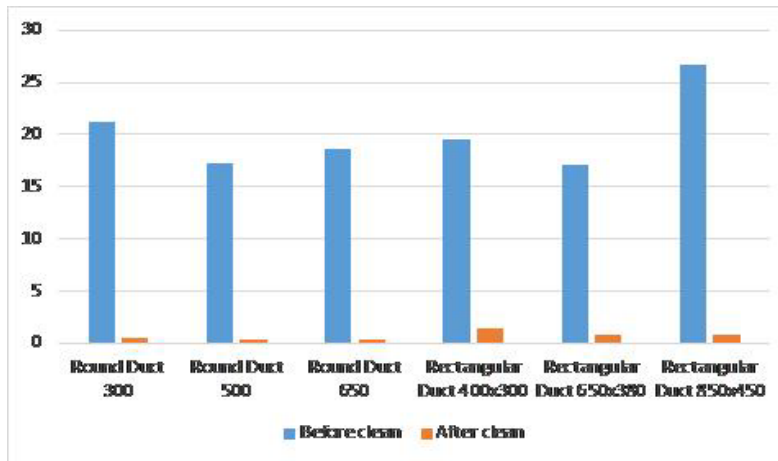


Fig. 3 Comparison of before clean and after clean values of duct [4]

Shankar Sapaliga [5] The issue of duct cleaning is covered in the paper “Duct Cleaning” by Shankar Sapaliga, which was printed in the Air Conditioning and Refrigeration Journal Issue in October–December 2005. In the context of air conditioning and refrigeration systems, the author discusses the significance of keeping ducts clean. Sapaliga gives a summary of the numerous pollutants, including dust, allergens, and mould, that can build up in ducts and their potential to have a harmful effect on indoor air quality.

The page discusses several ducts cleaning procedures, including manual, mechanical, and chemical methods. The importance of routine duct cleaning is emphasised by Sapaliga in order to maintain the best system performance, energy efficiency, and occupant health and comfort. The article provides professionals in the air conditioning and refrigeration business with knowledge and direction on the subject of duct cleaning.

Wootae Jeong *et al.*, [6] The development of an advanced trajectory control system for skid-steered duct-cleaning

mobile platforms is the main focus of the study by Jeong W, Jeon S, and Jeong D, “Advanced Backstepping Trajectory Control for Skid-Steered Duct-Cleaning Mobile Platforms,” which was published in Electronics in April 2019. They emphasise the value of accurate and effective control on mobile platforms to guarantee efficient duct cleaning and navigation. The control approach the researchers suggest for skid-steered platforms provides for better trajectory monitoring and manoeuvrability.

The study shows the design and implementation of the sophisticated control algorithm and examines the mathematical modelling of the mobile platform. Results from experiments show how the suggested control system can be used to improve duct cleaning operations and achieve accurate trajectory following. This research leads to the creation of more effective and dependable duct-cleaning systems while offering insightful information on the subject of mobile platform control.

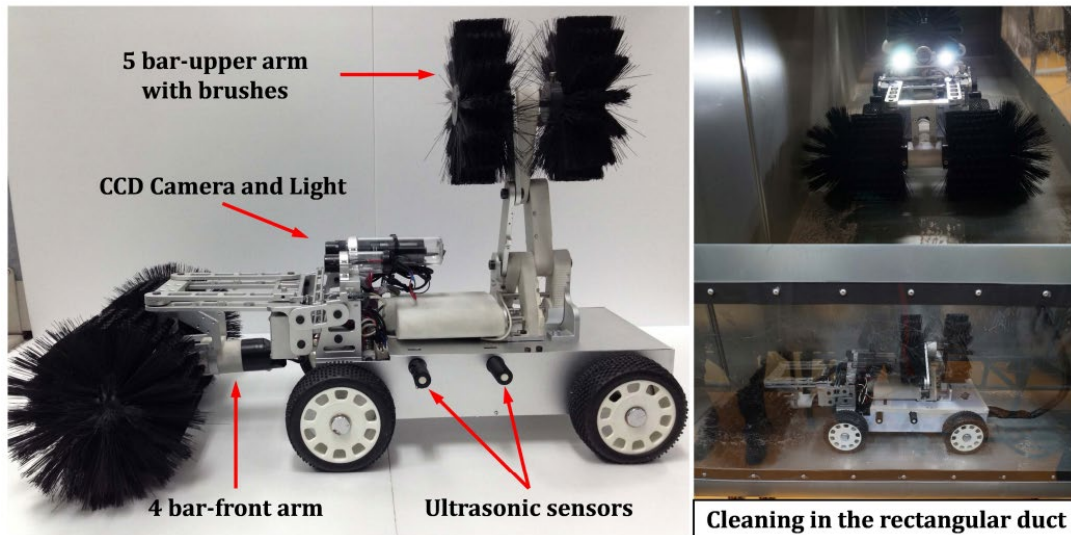


Fig. 4 Duct cleaning mobile platform [6]

Marina Mijanovic Markus *et al.*, [7] A study article on the creation of a robot specifically intended for cleaning ventilation ducts was given by Bubanja M., Markus MM., Djukanovic M., and Vujovic M. at the international conference “New Technologies, Development, and Applications” in June 2018. In order to achieve the best indoor air quality, the authors stress the significance of maintaining clean and effective ventilation systems. For duct cleaning, they suggest a robot-based alternative. The robot, which is outfitted with specialised cleaning equipment and sensors to properly navigate and clean ducts, is the subject of a discussion in the article that also covers its design and functionality. The authors place a strong emphasis on the necessity of automated solutions to increase the effectiveness and dependability of duct cleaning operations. The study advances the maintenance of ventilation systems and offers insightful information on the creation of robotic technology for duct cleaning applications.

2017 IEEE International Conference on Advanced Intelligent Mechatronics (AIM). The authors discuss the need for efficient cleaning methods in residential settings and suggest a robot that moves by peristaltic crawling. The report examines the robot’s design and deployment, emphasising its effectiveness at navigating and cleaning air ducts. The authors highlight the benefits of the peristaltic crawling motion, including the lower risk of contamination and improved manoeuvrability. Experimental findings and performance assessments show how well the robot cleans air ducts thoroughly and consistently. This study makes a significant contribution to the field of robotic residential cleaning and offers insightful information on the use of peristaltic crawling motion for cleaning air ducts.



Fig. 5 Robot for cleaning and inspecting ducts in 3D CAD format without any other equipment [7]

Y. Tanise *et al.*, [9] The research on the development of an air duct cleaning robot specifically created for housing applications was presented by Tanise Y, Taniguchi K, Yamazaki S, Kamata M, Yamada Y, and Nakamura T in the

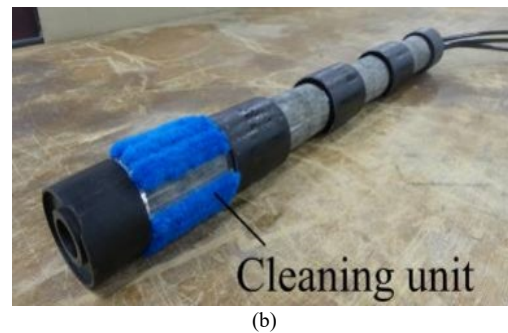
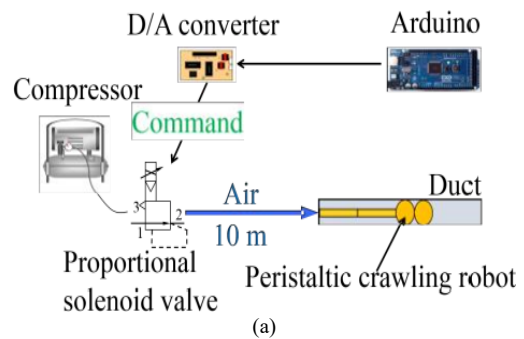


Fig. 6 (a) Control system of the peristaltic crawling robot (b) Appearance of the robot [8]

Alexey Bulgakov *et al.*, [10] The use of telerobotics for the examination and cleaning of air conditioning ducts is examined in the paper “Air Conditioning Ducts Inspection and Cleaning Using Telerobotics” by Bulgakov A. and Sayfeddine D., which was published in *Procedia Engineering* in 2016. The study emphasises how important it is to keep ducts clean and operating properly in order to have effective air conditioning systems. The authors suggest a telerobotic system that allows a robot to be operated and controlled remotely for duct cleaning and inspection duties. They talk about the system’s conception and execution, emphasising the use of teleoperation to get around the drawbacks of conventional manual techniques. In this study, experimental findings and case studies are presented to illustrate the viability and efficacy of telerobotic inspection and cleaning in diverse real-world contexts. The potential of telerobotics to increase the effectiveness and precision of duct inspection and cleaning operations is demonstrated in this research, which offers important new insights into the subject of air conditioning maintenance.

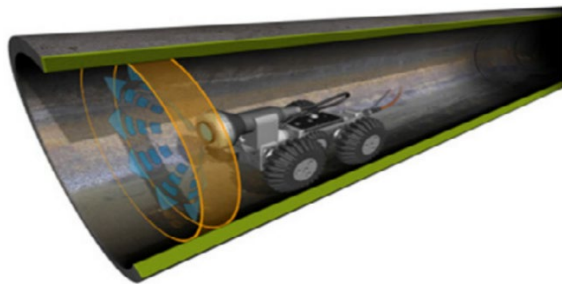


Fig. 7 Telerobotic concept design for air duct cleaning [9]

IV. CONCLUSION

Air duct cleaning robots may be used in a variety of locations including homes, offices, factories, hospitals, and other public venues. This illustrates how flexible and versatile these robots are for use in the air duct cleaning sector. the potential of air duct cleaning robots as a cost-efficient and efficient method of controlling indoor air quality in diverse situations. It also supports the notion that robots might make

air duct cleaning more practical and effective for a range of buildings and institutions. This is an effective way to illustrate how robots can affect the air duct cleaning industry as well as how they might benefit different society groups. The employment of air duct cleaning robots helps lower the annual cost of repairing and maintaining air duct systems. This is one of the potential benefits of using robots to clean air ducts since they would be able to improve the cleaning process’ effectiveness and efficiency, hence reducing the need for costly subsequent repairs or maintenance. Cleaning of air ducts Robotic cleaning can increase the performance and cost-effectiveness of the cleaning process while expanding the range of buildings and facilities that can use this service. They can also enhance interior air quality.

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