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Design and Development of AC Duct Cleaning Robot

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ABSTRACT
This document presents the design and development of anautonomous robot specifically engineered for cleaning air conditioning (AC)ducts. The necessity for such a robot system from the challenges associated withconventional manual duct cleaning methods, which are labour-intensive, time
consuming, and often inadequate in ensuring thorough cleanliness. The proposedrobot aims to address these limitations by leveraging robotics technology toautomate the cleaning process, enhancing efficiency, effectiveness, and safety.

Keywords- Autonomous, AC Ducts, cleanliness, robotics, efficiency.

I. INTRODUCTION

The design and development of an AC duct cleaning robot are driven by aconfluence of factors, including the increasing awareness of indoor air quality,the need for more efficient maintenance practices, and advancements in roboticsand automation technology. Traditional manual methods of duct cleaning oftenfall short in reaching all areas of the ductwork, leading to compromised airquality and reduced HVAC system efficiency. In contrast, the AC duct cleaningrobot offers a comprehensive solution by leveraging its autonomous navigationcapabilities and specialized cleaning mechanisms.

At the heart of its design is a focus on efficiency and effectiveness. Byautomating the cleaning process, the robot streamlines operations, reducing thetime and labour required for duct maintenance. Its ability to access confinedspaces and navigate complex duct configurations ensures thorough cleaning,removing dust, debris, and microbial contaminants that can accumulate overtime. This not only improves indoor air quality but also optimizes HVAC systemperformance, leading to energy savings and extended equipment lifespan.

II. LITERATURE REVIEW

The literature review delves into recent advancements and methodologies inAC duct cleaning, primarily focusing on the development of robotic systems forimproved efficiency, precision, and safety.

Ultra-wideband (UWB) integration revolutionizes duct cleaning robots,enhancing control and navigation in complex ducts. Myeong In Seo's[1] researchpromises autonomous operation, minimizing errors and manual intervention,thereby advancing efficiency and reliability in industrial and commercialsettings. Bu Dexu's[2] research introduces an adaptive robust control method forduct cleaning mobile manipulators, combining sliding mode control with fuzzywavelet neural networks (FWNN) to address uncertainties. This approachensures precise trajectory tracking in complex duct systems, improvingefficiency and reliability in industrial and commercial cleaning operations. PriyaDhengre's[3] research promotes non-destructive techniques in duct cleaning,employing a wirelessly controlled robot with sensors and probes to detect andeliminate contaminants while preserving duct integrity. This approach ensuresefficient cleaning, maintains indoor air quality, and extends HVAC systemlifespan, contributing to safer and more reliable cleaning methods withenvironmental and energy efficiency benefits.

Wang.Y's[4] paper introduces an autonomous air duct cleaning robot system,integrating monitoring and control devices to enhance efficiency andeffectiveness. This innovation promises streamlined operations, improvedcleanliness, and reduced maintenance costs for HVAC systems, marking asignificant advancement in duct cleaning technology. Chong Meng's[5] studyassesses a duct-cleaning robot's effectiveness and motion, emphasizingstandardized evaluation methods. It offers insights for refining cleaningmethodologies and enhancing system efficiency, advancing robotic duct cleaningtechnologies for industrial and commercial settings. Inayathulla's[6] projectpresents a robot system for cleaning dust in large-scale industrial AC ducts.

cleaning with DC motors, reducing time and costs while maintaining air quality.Ghantenavar's (2021)[7] research employs a wirelessly controlled robotwith sensors like ultrasonic and thermography to detect and remove dust, fungi,and flaws in air conditioning ducts non-destructively. Cleaning probes, such asscrubber blades, enhance efficiency and extend duct and cooling unit lifespan.Bulgakov's[8] paper explores telerobotic solutions to automate HVAC ductcleaning, aiming to enhance efficiency and worker safety, particularly inhazardous environments like hospitals. It discusses health regulations andproposes integrating telerobotics for enhanced cleanliness and reduced risks.Selvakumar's[9] research centers on non-destructive techniques for cleaningand maintaining air conditioning duct systems, aiming to Utilizing a night vision camera and adjustable duct size, the robot automatesprevent damage andenhance efficiency. Their wirelessly controlled robot, powered by batteries andequipped with wheeled and wall tire systems, removes dust, fungi, and foreignparticles while detecting flaws. Probes and infrared cameras ensure healthy airsupply by removing impurities and providing live views of duct interiors. Itssimple design enhances utility and applicability, addressing indoor air qualityconcerns.

Abdullah (2013)[10] proposes a mechanical robot to monitor ductconditions, collecting data on temperature, humidity, pollutants, and images.This data guides maintenance and ensures compliance with indoor air qualitystandards, offering a proactive solution to mitigate IAQ issues from neglectedduct maintenance. Jeong's[11] study introduces an autonomous robot withcompliance rolling brushes to improve indoor air quality in confined spaceslike subway stations. It aims to reduce operating costs for ventilation systemsby efficiently cleaning ducts, addressing contaminants that can harmpassengers' health. This highlight growing interest in robotic technologies forAC duct cleaning, offering opportunities for more efficient and sustainablesolutions in the future.

III.OBJECTIVES

As buildings become more sophisticated and reliant on HVAC (Heating,Ventilation, and Air Conditioning) systems for comfort and air quality control,the maintenance of these systems becomes increasingly important. Among thecritical maintenance tasks is the cleaning of air ducts, which can accumulatedust, debris, and even mold over time, leading to decreased efficiency andcompromised indoor air quality.To address this challenge, the design anddevelopment of an AC duct cleaning robot offer a promising solution. Theobjectives of such a robot are multifaceted and geared towards enhancingefficiency, effectiveness, and safety in HVAC system maintenance. Here aresome key objectives:

1. Design appropriate robot as per the requirement.
2. Develop a small working models according to design.
3. Analyse the performance of the robot of cleaning AC duct andremove that part.

IV. METHODOLOGY

1. CAD Model

In the design of the AC Duct Cleaning Robot using Fusion 360 software, ourapproach was to create a comprehensive 3D model that accurately representedthe robot's structure and components. We utilized Fusion 360's powerful toolsand features to develop detailed designs, taking into account variousconfigurations and potential obstacles commonly encountered in ductenvironments. To ensure versatility and adaptability, we created multipleconfigurations of the robot, each equipped with different obstacle scenarios.These scenarios included obstacles of varying shapes and sizes, such ascircular, rectangular, and cubical objects. By incorporating these obstacles into

our 3D models, we were able to simulate real-world duct environments andassess the robot's ability to navigate and manoeuvre effectively.

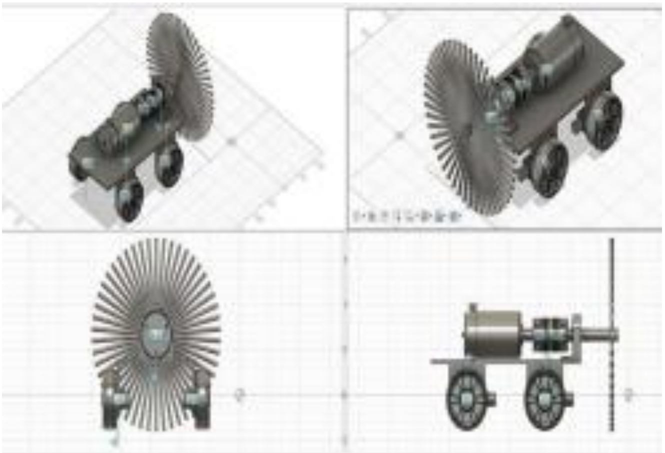

Fig 1. Design of prototype of AC Duct Cleaning Robot in Fusion-360

Throughout the design process, we paid close attention to factors such assize constraints, clearance requirements, and structural integrity. We optimizedthe placement of components to maximize space utilization while ensuring easeof assembly and maintenance. Additionally, we incorporated features to enhancethe robot's stability, durability, and overall performance in challengingconditions. By utilizing Fusion 360's simulation capabilities, we were able toevaluate the proposed designs and identify any potential issues or areas forimprovement. This iterative approach allowed us to refine the design iteratively,ensuring that the final AC Duct Cleaning Robot was well-suited for its intendedapplication and capable of meeting the demands of real-world duct cleaningtasks.

2. Design of Robot

For designing and developing of the AC Duct Cleaning Robot we havefollowed the systematic strategy to make our product reliable and within time.The methodology of our AC Duct Cleaning Robot is given as below

A. Selection of robot size

Based on duct size we decided chassis size.

Duct dimensions: (25 cm x 25 cm x 100 cm)

The chassis should fit within these dimensions and provide enough space forthe cleaning equipment. The chassis material is made of lightweight aluminiumalloy, weighing 270 g. The maximum payload, including cleaning equipment andelectronics, is estimated to be 4730 g.

Chassis dimensions:

The chassis needs to be compact enough to navigate through narrow ductswhile carrying necessary cleaning equipment. Materials should be lightweightand durable to withstand potential impacts and vibrations. Considerations for theshape and size of the chassis should allow for easy manoeuvring in confinedspaces and consider the weight of the chassis materials and the maximum payload(cleaning equipment) it needs to carry.

Duct Size: Measure the dimensions of the ducts where the robot will operate.Ensure the robot's dimensions allow it to navigate through these ducts effectively.Manoeuvrability: Choose a size that allows the robot to turn and move freelywithin the ducts without getting stuck or causing damage. Payload Capacity:Consider the size needed to accommodate cleaning equipment, electronics, andany other accessories required for the task.

weight evenly and positioning components strategically within the chassis, we can achieve better balance and stability during operation.

Fig 2. Actual Model of AC Duct Cleaning Robot

B. Selection of DC motor

Based on the weight of the robot and the weight of the brush. Motors shouldprovide sufficient torque for propulsion, especially in environments withpotential obstacles or debris. DC motors with encoders can offer precisecontrol and feedback, aiding in navigation and obstacle avoidance. Brushlessmotors might be preferred for their efficiency and reliability, reducingmaintenance needs. Calculating the required torque based on the weight of therobot and the friction coefficient between the wheels and the duct surfaces.Determining the maximum speed required for efficient cleaning and the powernecessary to achieve it. Consider the efficiency and power consumption ofdifferent motor options.

Torque requirement of 0.5 Nm to overcome friction and propel the robot inthe duct. The maximum speed required for efficient cleaning is 0.1 m/s. A DCmotor with a rated torque of 0.8 Nm and a maximum speed of 100 RPM isselected. Wheel RPM: 60. The robot's speed is determined by the wheeldiameter and RPM. Let's calculate it:

Wheel circumference = π * dia. = π * 6.5 cm ≈ 20.42 cmLinear speed = RPM * circumference / 60 = 60 * 20.42/ 60 ≈ 20.42 cm/sAssuming a friction coefficient of 0.2 and a total robot weight of 5 kg(including cleaning equipment):

Torque = (robot weight + payload) * coefficient of friction * radius of wheelsTorque = (5000+250)*0.2*3.25 = 3412.5 N-mm

C. Selection of brush

We have selected brush of diameter 20 cm based on duct size. Brushesshould effectively dislodge and remove dust, debris, and other contaminantsfrom duct surfaces. Consider materials that are durable, non-abrasive to ductsurfaces, and resistant to wear from repeated use. Calculating the surface areaof the brushes and the force required to dislodge contaminants based on thetype and amount of debris expected in the ducts. Estimating the wear rate ofthe brush materials and the expected lifespan before replacement is necessary.Brush diameter: 20 cm

Assuming a circular brush with a diameter of 20 cm, the cleaning area can becalculated:

Brush area = π * $(rad)^2$ = π * $(10cm)^2$ ≈ 314.16 cm^2.

D. Balancing of robot

Proper weight distribution is crucial for stability and manoeuvrability. Thecentre of mass should be positioned low to the ground to prevent tipping.Calculate the centre of mass of the robot based on the distribution ofcomponents and payload. Ensure the centre of mass is positioned low to theground, for example, at a height of 5 cm from the base. To balance the robot,we need to ensure that its centre of mass is positioned low to the ground andcentralized within the chassis. Let's distribute components and payload evenlyto maintain balance. Assuming the chassis weighs 270 g and the cleaningequipment and electronics weigh 4730 g, the total weight is 5 kg. The centreof mass should ideally be in the centre of the chassis, vertically positionedaround 5 cm from the bottom (half the chassis height). By distributing the By calculating the centre of mass by distributing the weight of components (chassis, motor, brush, electronics) evenly within the robot chassis. Position heavy components closer to the centre and lower to the ground to improve stability.

V. EXPERIMENTAL RESULTS

As the third objective of the project is to analyse the performance ofthe robot in cleaning AC duct and remove that cleaned part, we did theexperiment of travel in m/min with respect to dust collected in gram at constantbrush rpm of 300, which is inversely proportional to each other. As the travelspeed of robot increases the amount of dust collected is minimum and slowly thespeed decreases the amount of dust collected is maximum.

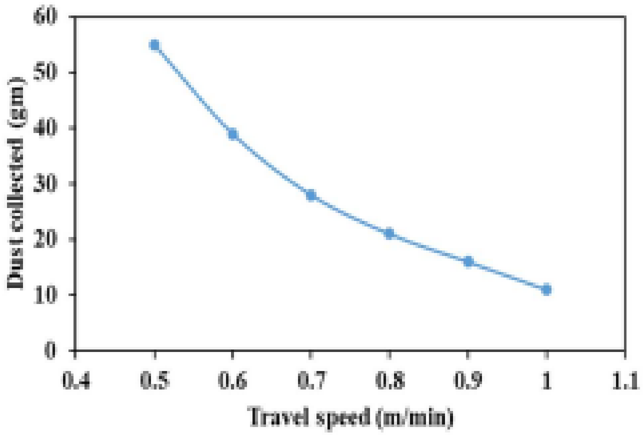

Fig. 1. Effect of travel speed on amount of dust collected

Next to that we experimented the varying brush rpm with respect toarea to be cleaned in m2 at constant travel speed of 0.5 m/min which is directlyproportional to each other. The speed of brush is minimum then area to be cleanedis less and speed increases slowly then area to be cleaned if also more.

VI. ACKNOWLEDGMENT

We would like to express our sincere gratitude to the researchers andscholars whose work has contributed to the body of knowledge in the field ofHVAC system maintenance and robotic technologies. Their insightful studiesand innovative solutions have laid the foundation for the development of theAC duct cleaning robot described in this document. Additionally, we extendour appreciation to the developers of Fusion 360 software for providing arobust platform for CAD modelling and simulation, which proved invaluablein the design and optimization of the robot. Finally, we acknowledge thesupport and guidance of our colleagues and mentors throughout the project,whose expertise and encouragement have been instrumental in its success.

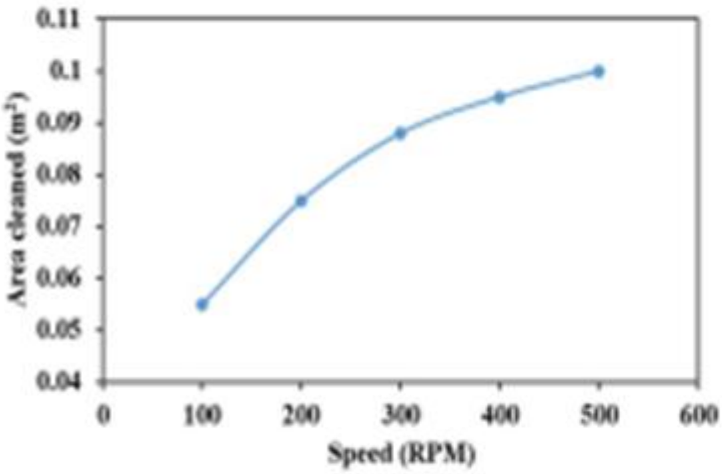

Fig. 2 Effect of brush speed on area cleaned

VII. CONCLUSION

The development of an AC duct cleaning robot represents a significant advancement in HVAC system maintenance, driven by the imperative to improve indoor air quality, enhance efficiency, and ensure safety.

The comprehensive literature review underscores the evolution of robotic technologies in this domain, while the outlined objectives and methodologiesdetail a systematic approach to design, development, and performanceanalysis. Experimental results validate the robot's effectiveness in cleaningducts efficiently, highlighting its adaptability to different cleaningrequirements. Overall, the AC duct cleaning robot offers a promising solutionto address the challenges associated with duct maintenance, paving the way for improved indoor air quality and prolonged HVAC system lifespan.

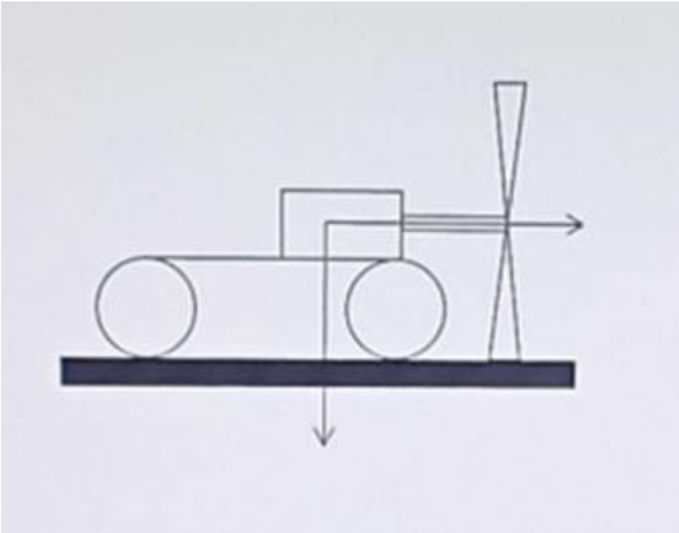

Fig 3. Balancing of Weight

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