DEPARTMENT OF COMPUTER SCIENCE,

FACULTY OF SCIENCE,

THE UNIVERSITY OF IBADAN,

NIGERIA.

CSC 574

ONASOGA OLUWAPELUMI IDRIS

214909

RESEARCH TOPIC:

Transforming Vacuum Cleaners to an Intelligent system with the Design of an Autonomous House Cleaning Robot

Abstract

In recent times, there has been an increase in the demand for automation in our households, basically, domestic environments, and as a result, it has led to advancement in robotics, most especially in the development of house-cleaning robots. The vision when it comes to the creation of these robots is to remove the burden of household chores and at the same time be efficient, precise, and convenient. The purpose of this paper is to deliver a well-revised approach to designing an autonomous house-cleaning robot, focusing on the integration of different technologies which includes machine learning, computer vision, and sensor fusion which attaches the components needed by an intelligent system to display intelligent behavior such as perception, learning, knowledge representation, planning and execution, the components are also needed to enable autonomous operation in dynamic, unstructured home environments.

The proposed robot design integrates various key components: perception systems for environment understanding, mapping, and localization, decision-making algorithms for task planning and navigation, and cleaning mechanisms for precise and efficient dirt and debris removal. A central feature of the system is to use of localization and mapping techniques to create real-time maps of indoor spaces, allowing the robot to navigate unknown environments autonomously while avoiding obstacles and optimizing cleaning paths. In addition, the robot will be equipped with object recognition capabilities, enabling it to identify and avoid fragile or valuable household items.

To improve adaptability and performance, a deep reinforcement learning framework is employed, allowing the robot to learn from its interactions with the environment and improve its cleaning efficiency over time. Reinforcement learning is chosen because it involves a feedback system where positive reviews will be used as an incentive while negative reviews are also learned from. The learning-based approach also enables the system to adapt to different types of floor surfaces, furniture arrangements, and jumble, thus giving it a wide range of usability across various household settings. Furthermore, the robot system will incorporate edge detection and

floor type recognition algorithms to distinguish between cleaning zones such as carpets and concrete floors, and apply appropriate and precise cleaning methods.

This study will also include hardware challenges in designing these kinds of robots, and they should have well-optimized power efficiency. The performance of these robots will be evaluated through a series of experiments, and metrics such as cleaning coverage, and completion time will be measured and analyzed. The results demonstrate that the proposed system offers a very significant improvement in autonomous cleaning over traditional robotic vacuum cleaners.

The paper concluded by discussing the limitations of the current design, which included challenges such as real-time decision making in jumbled environments and battery constraints. The development of a fully autonomous and intelligent house-cleaning robot has the potential to revolutionize domestic automation and seriously reduce the time and effort required for household maintenance

CHAPTER 1

INTRODUCTION

A very notable household chore is floor cleaning which is often considered unpleasant, difficult, awkward, and boring (N, Mitchel, 2016). In most cases, cleaners are hired to do the task rather than the household residents do it. The discomfort posed by this recurrent chore necessitated the development of a vacuum cleaner that could assist humans with such a task. A vacuum cleaner is an electromechanical appliance commonly used for cleaning floors, furniture, rugs, and carpets by suction. An electric motor inside the appliance turns a fan which creates a partial vacuum and causes outside air to rush into the evacuated space. This forces any dirt or dust near the nozzle into a bag inside the machine or attached to the outside.

Current vacuum cleaners, although efficient, are rather bulky and therefore require large manpower for proper functioning. The earlier known cleaners are those of Daniel Hess of Iowa (in 1860) and Ives W. McGaffey of Chicago (in 1868). While the former used bellows to generate suction and gathered dust with a rotating brush, the latter worked with a belt driven by a hand-cranked fan making it awkward to operate. In the late 1990s and early 2000s, more efficient sweepers equipped with limited suction power were developed. Some prominent brands are iRoomba, Neato, and bObsweep. Depending on the design target, robotic vacuum cleaners are appropriate for offices, hotels, hospitals, and homes. However, most cheap cleaners need a better cleaning pattern algorithm for efficient functioning while the smart ones are rather costly, and thus beyond the reach of most homes. These challenges were carefully considered while designing an autonomous house-cleaning robot described in this paper.

The growing advancement in robotics and artificial intelligence has impacted a lot of industries from manufacturing to healthcare to transportation and logistics. Recently, the rise in autonomous systems has penetrated the domestic space, with the need for automating household

tasks. The development of autonomous house-cleaning robots will save time and improve the quality of life for individuals.

Designing an autonomous house-cleaning robot requires a well-thought-out approach, combining innovations in artificial intelligence, machine learning, computer vision, sensor fusion, and robotics engineering. At the center of such a system should be the ability to perceive, learn, represent knowledge, understand its environment, make intelligent decisions, and execute the cleaning tasks efficiently. This includes recognizing different types of surfaces, identifying and avoiding obstacles, and creating cleaning strategies based on their surroundings dynamically. A fully intelligent and autonomous house-cleaning robot should also have self-learning capabilities, allowing it to improve over time through interactions with its surroundings and feedback on its performance.

In this paper, I will present a well-revised approach to designing an autonomous house-cleaning robot capable of navigating complex household environments and performing house-cleaning tasks with minimal human intervention. The proposed system aims to overcome the limitations of current robotic cleaning solutions by improving their autonomy, flexibility, and efficiency.

PROBLEM STATEMENT

Although much progress has been made in autonomous household cleaning robots, the current systems are still far from achieving true autonomy, efficient path planning, and complete cleaning coverage in the very complex and ever-changing environment of a home. These robots can't seem to master obstacle detection, efficient path planning, or adaptation to various floor types, which results in spotty cleaning and constant babysitting. There needs to be smarter systems that can independently adapt to different home environments, conserve energy, and clean more effectively.

AIM

The goal of this research is to build and test an intelligent autonomous housecleaning robot, incorporating improved sensory systems, intelligent decision-making algorithms, and efficient cleaning components in order to perform self-sufficient cleaning in a home environment, with the least amount of energy and user interaction.

CHAPTER 2

Literature Review

A Technological Survey on Autonomous Home Cleaning Robots

In this present era, people live a very busy life. People in cities have irregular and long working times. In such a situation a person will always find ways of saving time. household chores are the ones that are most dreaded. And cleaning a home tops the list. It is not only time-consuming but also very tiring. Especially for working women, it becomes difficult to handle

both home and office work together. She has to do the household chores in the morning, go to work and do the work there, and return home in the evening to again start her chores at home.

Thus she lives a dual life. In this dual life, we thought of gifting her away of saving some of her precious time. The requirement for a House Cleaning Robot is born. For saving time we needed an automatic system that cleans on its own without human interventions. Also, we did think about how to aid people with physical disabilities. Since we had to do this, we knew that we needed a cleaning system that could work in accordance with what we say, thus helping a physically disabled person.

- **BATTERY-LIFE AND RELIABILITY**

Battery reliability is a frequently-mentioned complaint on vacuum cleaners and other third-party customer review websites. Battery replacements from robots cost a significant fraction of the purchase price of a new robot, though compatible third-party batteries are available at a lower price. All batteries will gradually lose energy capacity, resulting in shorter cleaning runs, eventually necessitating replacement. Robot batteries are end-user-replaceable within minutes. When a Robot owner is absent for an extended period (such as a vacation or due to illness), automatically scheduled cleaning runs should be canceled. For example, if it becomes entangled

and stops with an error sound on an unattended session, the battery will remain deeply discharged for an extended period, often resulting in permanent damage to the battery. D. ACC The house cleaning robot uses a microcontroller to detect obstacles and manipulates its direction as per the inputs from infrared sensors mounted in front, right, and left of the robot or the digital signal processor. The heart of the system is a microcontroller. It is programmed to accept inputs to sense obstacles around it and control the robot to avoid any collisions. There are 4 IR sensors used in this project- one at the front, and the remaining on the left, right, and back of the robot to detect obstacles, if any. In case of an obstacle or a potential collision, the microcontroller controls the wheels of the robot by a motor driver to avoid collision. The vacuum cleaner mounted on the robot performs the cleaning process. Auto mode: In this mode, the microcontroller is programmed in such a way that it takes the decision and changes

the path of the robot as per the sensor inputs to avoid obstacles. A timer is used to set the time limit for the cleaning process.

Perception System and Object Recognition

A key challenge in autonomous cleaning robots is their ability to perceive and understand their environments. Recent systems utilize a combination of sensors, including infrared, and ultrasound for environmental mapping and object detection. The literature on sensor fusion techniques, such as that by Borenstein and Koren (1991), emphasizes the importance of combining multiple sensor modalities to achieve more robust obstacle avoidance and surface detection. In Modern times, there has been a growing focus on integrating computer vision techniques for more advanced perception.

Mur-Artal and Tardós (2015) presented ORB-SLAM, a visual SLAM method that uses cameras to detect and track visual features in the environment, which improves localization accuracy. Furthermore, Redmon et al. (2016) developed the YOLO (You Only Look Once) object detection algorithm, which enables real-time object identification and classification. These advancements

enable modern cleaning robots to recognize and avoid fragile objects like vases or toys, as well as identify cleaning zones more effectively.

Despite these advances, object recognition in real-world settings remains difficult because to differences in lighting, occlusion, and the variety of household items. According to Zhou et al. (2018), robots frequently struggle to recognize smaller objects or those with complicated geometries, resulting in insufficient cleaning or collisions.

Machine Learning and Adaptive Behaviour

With the developments of machine learning in recent years, especially in the field of deep reinforcement learning (DRL), it is possible to make significant improvements in the autonomy and intelligence of domestic cleaning robots. The pioneering work by Mnih et al. (2015) showed that DRL could be applied to robotic control, with agents learning the best actions by a process of trying and failing in a simulated world. This idea is now used in home robots to allow learning or adaptive cleaning methods that get better and better with information from the surrounding world.

A study by Zeng et al. (2018) showcased the application of DRL in robotic vacuum cleaners, enabling them to efficiently optimize their cleaning paths and adapt to changing environments without relying on predetermined behaviors. DRL also enables robots to be able to deal with different flooring surfaces (carpet, hardwood, etc. by actually learning and adapting cleaning methods (suction power, brush speed, etc. It is expensive and time-consuming to train these models in the real world and that is why Levin et al. (2016) stressed the advantage of using a simulation world to speed up the learning process and then apply the models to the real world.

Simultaneous Localization and Mapping (SLAM) in Domestic Robots

As consumer expectations grew, so did the need for more advanced navigation techniques. A pivotal advancement in autonomous robotics was the development of Simultaneous Localization and Mapping (SLAM) algorithms. SLAM enables a robot to build and update a map of its

environment while simultaneously tracking its own location within that map. Early implementations of SLAM in domestic robots were investigated by Thrun et al. (2005), who demonstrated the feasibility of using laser rangefinders and depth cameras to allow robots to navigate dynamic indoor environments more accurately.

The integration of SLAM into robotic cleaners, such as iRobot's higher-end models and Neato Robotics' vacuum cleaners, improved cleaning efficiency by allowing these robots to plan optimized paths based on real-time maps. These systems were able to cover more floor space systematically and with fewer overlaps. However, Montemerlo et al. (2007) pointed out that while SLAM improved navigation, many systems still struggled with real-time obstacle detection, and their performance degraded in highly cluttered or dynamic environments where furniture or objects were frequently moved.

Challenges and Future Directions

Even though there have been many strides in autonomous house-cleaning robots, there are still many problems. Bonetto et al. (2019) outlined some major problems including real-time obstacle avoidance in cluttered rooms, efficient multi-room travel, and the capability to recognize the wide variety and constant change of home structure. Plus, almost all of today's systems need some sort of human intervention at some point, like taking out the trash or unraveling wires, so they aren't truly autonomous.

The next step in research will probably be on human-robot interaction, systems that recognize verbal or gesture commands, as Vazquez et al. (2020). And the creation of more efficient designs, and the integration of self-energizing mechanisms (docking stations with wireless charging) will make them all the more convenient. Furthermore, edge computing and cloud integration will probably advance, so robots will be able to process more data on the spot or in a cloud, and therefore make better split-second decisions.

CHAPTER 3

SYSTEM COMPONENTS

For an autonomous house-cleaning robot to work properly many systems must work together flawlessly, each system performing a vital role in the overall function of the robot's intelligent navigation and decision making and cleaning abilities. These would be the sensing system, the decision-making algorithms, the motion planning and control, the power management, and the actual cleaning mechanisms. In this chapter, we delve into these components, discussing their roles, underlying technologies, and how they interact to create an effective autonomous cleaning system.

PERCEPTION SYSTEM

The basis of any autonomous robot is its ability to sense and interpret the world around it. The perception system in an autonomous house-cleaning robot is responsible for sensing the surrounding environment, detecting obstacles, identifying different floor types, and recognizing objects to avoid collisions or damage. This part includes many sensors, cameras, and data processing algorithms.

1. **SENSORS**

Robust sensor integration is crucial for effective environment perception. The average autonomous house-cleaning robot uses a combination of the following sensors:.

- ***Infrared and Ultrasonic Sensors:***

  These sensors work by sending out sound or light waves and detecting the nearby objects by the emitted signals that are reflected back. I'm sure they're for sensing walls or furniture or anything in it's cleaning path. The Roomba series has long utilized these sensors for primary movement and obstacle evasion.

- ***LiDAR (Light Detection and Ranging):***

  LiDAR sensors work by shooting out laser beams and determining how long it takes for the light to hit an object and reflect back, creating extremely detailed maps of the environment. This enables more precise localization and real-time map-building. LiDAR is a critical component of SLAM (Simultaneous Localization and Mapping) algorithms that allow robots to function in congested, changing environments.

- *RGB and Depth Cameras:*

  These are 3D cameras that give the robot a visual and depth feel of the environment. Especially carpeted or tiled floors, cameras are really good at recognizing objects, edges, like stairs, and specific areas of interest. They also incorporate Stereo Vision into newer systems to build a truer depth map.

- ***Bump Sensors:***

  These are simple contact sensors, they sense when they collide with something. Although bump sensors are reactive rather than proactive, they are essential for systems that rely on last-resort detection of obstacles.

2. **OBJECT RECOGNITION**

With its sophisticated object recognition abilities, the robot can easily distinguish between various objects and materials. Not to mention it prevents the destruction of vases or toys, but

more importantly, it allows one to recognize certain cleaning areas. For instance, in some of the newer cleaning robots, deep learning techniques have been applied, such as the YOLO algorithm, which performs real-time object detection and classification. With the use of pre-trained models, these algorithms can quickly recognize objects, thus allowing the robot to adapt its cleaning plan.

3. ENVIRONMENTAL MAPPING

One of the most important parts of the perception system is environmental mapping. Most autonomous house-cleaning robots today use Simultaneous Localization and Mapping (SLAM), which allows them to build a map of their environment while keeping track of their location within it. The SLAM algorithm uses data from sensors like LiDAR or cameras to create a continually updated, precise map. The map is a necessity because without it one would have to wander through large/complicated areas and risk cleaning the same spot twice.

DECISION MAKING AND TASK PLANNING

In order for an autonomous house-cleaning robot to work properly it must make "smart" decisions about where to clean, how to clean efficiently, and how to avoid obstacles. The control portion uses planning algorithms and AI-based methodology to perform these tasks.

1. PATH PLANNING

The robot's capability to plan efficient trajectories is the basis for its autonomy. For example, path planning algorithms like A* (A-star) or Dijkstra's Algorithm determine the most optimal path through space using real-time sensor data from the robot. These algorithms try to optimize the amount of cleaning coverage they do with the least amount of wasted movements.

For instance, RRT (Rapidly-exploring Random Trees) is used as a path-planning algorithm to account for dynamic obstacles, allowing the robot to be at home amongst furniture that has been moved, or pets and people. The robot constantly changes its course from the new information it receives from its environment so that it can cover as much area as possible.

2. NAVIGATION AND OBSTACLE AVOIDANCE

The robot has to go around obstacles in real time in order to move through complex household environments. It uses sensors and cameras as input and uses reactive and predictive methods for navigation. Reactive algorithms like Vector Field Histograms (VFH) allow the robot to steer away from objects as it is dynamically sensing them. For example, Kalman Filters, give the robot the ability to predict.

MOTION PLANNING AND CONTROL

Motion planning and control systems allow the robot to actually move around and balance itself with great precision. These allow the robot to move fluidly across various textures and not have sudden starts or slides.

1. MOTOR CONTROL

Pretty much all of the self-propelled house cleaning robots use brushless DC motors because they are highly efficient and provide very accurate movement and rotation. These motors control the wheels and brushes, allowing the robot to roll fwd, back, or spin in place. The control algorithms are PID (Proportional-Integral-Derivative) controllers that allow for smooth movement and precise path following.

2. **SURFACE ADAPTATION**

One challenge in house cleaning is the need to adapt to different surfaces—rugs, carpets, hardwood floors, or tiles. This is done through real-time modifications to the robot's cleaning mechanisms, for example by changing the suction power, or altering the speed of the brush whenever the sensors dictate. Such as when the robot is over a carpet it turns the suction up but when over a hard floor it turns the suction down to save energy and make less noise.

POWER MANAGEMENT AND BATTERY SYSTEMS

The issue of power control is a very important one in autonomous house cleaning robots because they will have to operate on batteries for long periods of time. This means that the robot will clean more before having to recharge, which is good.

1. **BATTERY TECHNOLOGIES**

Li-ion or NiMH batteries power most robots, which have a high energy density and can operate for a fairly long time. But these batteries need to be conserved, to maintain a good balance between cleaning ability and energy use.

2. **ENERGY-EFFICIENT ALGORITHMS**

Cleaning robots today use energy-efficient algorithms to clean more efficiently. For example, when it senses that it is in a less dirty area, it could slow down or even turn off some of its suction power or movement speed, and this would save battery life but would not compromise its cleaning abilities. Even more efficient are energy-aware scheduling algorithms which enable the robot to prioritize some rooms over others and clean with a lesser intensity when the battery charge is low.

All of today's house cleaning robots have the ability to self-charge, meaning that when their battery gets low they will automatically make their way back to the docking station. Higher models, with the use of slam-based localization and memory mapping, can remember where they left off once they are done charging and continue cleaning.

CLEANING MECHANISMS

The physical cleaning mechanisms are probably the most obvious and significant part of the robot's purpose. Some of these methods involve brushes, some suction, some filters, and some even more specialized equipment such as mopping attachments or UV sterilizers.

1. BRUSHES AND SUCTION SYSTEMS

The whole rotation brushes and sucking things up thing is pretty much the norm with these robotic cleaners. The main rotating brushes knock up dirt from floors and carpets, and the side brushes sweep along the edges and corners. The debris is then captured by a suction mechanism that pulls the dirt into a collection bin.

2. HEPA Filters and UV Sterilization

Some of the more sophisticated models even use High-Efficiency Particulate Air (HEPA) filters to capture minute particles and allergens, thereby enhancing indoor air quality. Another thing, some high-tech robots have UV sterilization units built into them so that when it cleans the floor it not only cleans but also sterilize, and for households with health freaks that's a two-in-one.

3. WET AND DRY CLEANING

Although older robotic vacuums are only designed for dry cleaning, the newer ones have the option of wet cleaning, including mop attachments. These types of robots can squirt water or cleaning liquid onto hard flooring and wipe up dirt with microfiber cloths. Robots that perform wet cleaning and dry cleaning depending on the nature of the surface would be a more complete answer.

CONCLUSION AND FUTURE WORKS

In the past few years, the field of autonomous home cleaning robots has come a long way, with great improvements in sensor technologies, intelligent decision-making, and adaptive control systems. From the days of the dumb, pre-programmed machines to the days of the smart AI-controlled robots that can maneuver through the house with ease. With the incorporation of sensing systems such as LiDAR, RGB-D cameras, infrared sensors, and the use of sophisticated algorithms such as SLAM for mapping and deep learning for object recognition, robots have been able to do cleaning tasks without much human intervention.

However, despite these advancements, several challenges persist. Many of today's systems have trouble making real-time decisions in very fluid environments, especially when moving obstacles are present, e.g. dogs and people. Also, the effectiveness of cleaning mechanisms, especially in houses with different kinds of flooring or lots of junk is another thing that needs improvement. Most robots use simple suction and brush methods, which don't always adjust to different flooring such as carpets, hard floors, or tiles. Energy conservation is also a big issue, the longer cleaning sessions seem to run down the battery, which needs charging, which in turn stops the cleaning process.

In answer to these problems, this research has developed a complete design that encompasses state-of-the-art perception, decision-making, motion control, and energy management systems. The system uses AI techniques such as deep reinforcement learning and adaptive algorithms to achieve superior obstacle avoidance, path planning, and adaptive cleaning performance based on the degree of clutter in the environment. It also includes energy-saving scheduling algorithms and smart surface adaptation to maximize working time without compromising cleaning performance.

While this design presents a robust framework for autonomous house-cleaning robots, there remains ample opportunity for future improvement and innovation. Key areas for future work include:

FUTURE WORK

- **Enhanced Real-Time Object Recognition**

One of the key areas for further investigation is real-time object recognition and avoidance. Systems today can recognize simple things around the house, but the speed and precision of object recognition could be better. More advanced computer vision algorithms should be incorporated in future work, possibly using CNNs (convolutional neural networks) trained on much larger datasets of common household objects. That way the robots can recognize and distinguish between their toys and shoes and wires and whatnot, and they can move more accurately in a messy room. The second idea is to incorporate gesture recognition for user commands like they have been using in some of the human-robot interaction systems so that the user can easily tell the robot what to do without having to go through an app or a manual interface.

- **Advanced Dynamic Environment Adaptation**

Existing cleaning robots are stumped by constantly changing surroundings. It must be constantly modifying its path of travel when obstacles like chairs or pets or humans move. Future systems could benefit from more sophisticated predictive algorithms that not only detect moving obstacles in real-time but also anticipate their future movement. These algorithms could be enhanced with data from additional sensors, such as ultrawideband (UWB) positioning systems or radar-based sensors, to track motion in real-time. Also, the use of cooperative AI structures would enable the robots to converse with other intelligent appliances around the home (smart cameras, thermostats) have a much better sense of the environment and avoid more collisions.

- **Multi-Room Coordination and Task Prioritization**

They should design the robots of the future to clean more than one room at the same time. Current systems often require manual intervention to clean different rooms or rely on basic zone mapping, which can be limited. With better multi-room coordination and some dynamic task

prioritization algorithms, robots could figure out for themselves what rooms/zones need the most cleaning at what times (maybe it's based on how much dirt is detected, or what time of day it is). For example, the robot should know to focus on kitchens and living rooms at certain hours and procrastinate with guest rooms and whatnot.

● **Continuous Learning and Adaptation**

Another interesting field of future research is in giving robots the ability to learn continually and adjust themselves based on what they experience. Some type of reinforcement learning could be used so that the robot would actually get better at cleaning the more it does it because it would learn from previous experiences. For example, if it noticed that certain places get dirty more often than others, or that some places always seem to be in the way, it would modify its performance accordingly and get better and better with time. Additionally, allowing users to provide feedback (e.g., marking certain areas as problematic) could guide the robot's learning process.

Conclusion

To sum it all up, although great strides have been made in the field of autonomous housekeeping robots, much more research is needed in order to overcome the hurdles of real time object recognition, dynamic adaptation, power conservation, and room-to-room prioritization. Using advanced AI techniques, machine learning, and more sophisticated sensor arrays, future autonomous cleaning robots will not only be much smarter and adaptive, but will also provide higher performance and greater convenience to the user. A vision of a truly independent, intelligent, energy conserving cleaning assistant is attainable, but it will take more than that, constant innovation and interdisciplinary research amongst robotics, AI, and energy management.

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