I Clean: A Prototype Solar Vacuum and Floor Cleaner Robot

Angelie D. De Villa, Jhins C. Aller, Grald V. Anyayahan & Aiza Comahig

The world is currently experiencing a period of remarkable technological advancement, profoundly impacting the daily lives of the current generation. Modern technologies provide enhanced productivity, improved time management, and simplified lifestyles (Diawati et al., 2023; Chuang et al., 2025; Ra et al., 2019; Rasool et al., 2022). Among these technologies, artificial intelligence (AI) has emerged as a key area of study, focusing on giving computers the ability to perform intellectual tasks traditionally reserved for humans. Recent advancements in AI have significantly influenced societal behavior and productivity, enabling improved labor efficiency, reduced labor costs, optimized human resource allocation, and the creation of new employment opportunities (Kassa et al., 2025; Wang et al., 2024; Georgieff & Hyee, 2022; Venugopal et al., 2024; Babashahi et al., 2024; Liu & Li, 2025; Chuang et al., 2024).

Nowadays, robots have become increasingly common in manufacturing, packaging, shipping, research laboratories, quality control, and many other industrial and consumer sectors. They are particularly valuable for performing tasks that are dull, dirty, or dangerous, such as floor cleaning, which is often considered tedious and labor-intensive (Takayama et al., 2008; You et al., 2025). For instance, improper waste management and ineffective cleaning practices can have detrimental effects on health and the environment. Cleaning involves the removal of dust, pathogens, and other contaminants from a space or object. While some cleaning tasks are simple, others are challenging, particularly in large areas that require multiple personnel. Hence, advances in robotics offer potential solutions to these challenges. Robots, as autonomous machines, can perform tasks without direct human intervention, even if they do not mimic human appearance or behavior.

In response to these challenges, this study aimed to develop a solar-powered floor-cleaning robot capable of cleaning large outdoor areas, patios, public restaurants, and extensive campuses with minimal human labor and reduced need for frequent recharging. The system was designed to assist in emergencies while promoting efficiency and sustainability. With today's busy lifestyles, maintaining cleanliness in homes and surrounding areas is increasingly difficult. Conventional vacuum cleaners still require human operation, and social distancing measures further limit the ability to perform manual cleaning, exposing people to allergens, dust, and potential health risks such as colds, coughs, rashes, and other respiratory issues.

The study's goal is to innovate an autonomous, efficient, and environmentally friendly floor-cleaning robot capable of automatically removing dust and dirt, reducing manual effort in scrubbing and sweeping, and enhancing traditional cleaning methods. This prototype integrates innovation, defined as the application of new technologies or processes to improve products or services and create new value (Nurjaya et al., 2021). In the context of household cleaning, automation and robotics have become essential for adapting to modern life, allowing routine chores to be completed efficiently with minimal human intervention.

To achieve practicality and affordability, the prototype employs Arduino technology, enabling simple and effective automation of cleaning tasks. By leveraging AI and automation, the system addresses limitations in conventional floor cleaning techniques and enhances living conditions (John et al., 2022). Additionally, the robot is powered by solar energy, a sustainable, environmentally friendly, and cost-efficient energy source, supporting long-term operation without reliance on conventional electricity.

Modern robot vacuums have evolved significantly and are capable of improving household life by effectively removing dust, allergens, and debris, surpassing the performance of traditional hand-operated vacuums. They provide users with more free time while promoting cleaner, healthier living environments. The primary objective of this prototype is to develop a solar-powered vacuum and floor-cleaning robot that can autonomously collect dry dust particles and mop floors without human intervention, thereby improving household cleaning efficiency and overall quality of life.

Theoretical Framework

Vacuum Cleaner Market Overview

The Philippines vacuum cleaner market, according to research, is projected to expand between 2020 and 2026 (Expert Market Research, n.d.). Technologies such as robotic vacuum cleaners are becoming increasingly common as part of the "digital revolution" in domestic life (Nicholls & Strengers, 2019). In the pursuit of the "smart home," numerous automated appliances are being introduced to the market, offering more ecologically friendly, convenient, safer, and enjoyable living environments. Recent research has focused not only on improving the cleaning capabilities of these robots but also on enhancing their interactivity with users (Liu et al., 2024; Malobický et al., 2025; Liu et al., 2024; Muthugala et al., 2020). Interactive elements that allow robots to communicate their status and needs are increasingly valued, as the lack of such communication can reduce the quality of human-robot interaction.

Development of Smart Vacuum Cleaners

The study by Sukumaran et al. (2022) explored the development of a solar-powered, Bluetooth-enabled intelligent vacuum cleaner using an Arduino microcontroller. The system integrates input from a Light Dependent Resistor (LDR) sensor and an ultrasonic sensor to determine the vacuum's navigation path. The device can automatically recharge via a solar panel when the battery is low or after cleaning, and it sends Bluetooth alerts to notify the user when a cleaning cycle is complete. Compared to traditional corded vacuum cleaners, this design offers faster cleaning, energy efficiency, and broader applicability, including use in the food industry, parks, and other public spaces.

In another study, Yatmono et al. (2020) developed an "Intelligent Floor-Cleaning Robot" capable of navigating, vacuuming, dusting, and polishing floors. The robot is equipped with Omni wheels, a vacuum, and floor-polishing motors, controlled via an Arduino microcontroller and software environment, enabling automated operation and efficient floor maintenance. Similarly, Sarmast et al. (2020) integrated both remote operation (via an Android smartphone) and autonomous cleaning modes. The system monitors battery voltage and prevents overcharging, alerting users via text messages when cleaning is completed. Advantages include prolonged motor life, energy efficiency, and reduced operational risks.

Automatic Floor Cleaners

Automatic floor cleaners are designed to perform cleaning tasks with minimal human intervention. Jain et al. (2017) describe a system that navigates autonomously while vacuuming designated areas. Ultrasonic sensors detect obstacles and prevent the robot from falling off elevated surfaces, while side brushes sweep debris toward the suction mechanism. The robot's movement is powered by DC motors controlled via an H-Bridge Configuration Driver (L293D), enabling forward and reverse navigation. These devices provide efficient, safe, and user-friendly cleaning solutions, saving both time and effort.

Solar Energy Integration

The use of solar energy enhances the sustainability and efficiency of robotic cleaners. Kabir et al. (2018) discuss the potential and prospects of solar energy, emphasizing its capacity to meet future global energy demands and its environmental benefits. Adeyoyin et al. (2019) explored solar-powered systems for ICT infrastructure in Nigerian universities, highlighting widespread knowledge and acceptance of solar energy as a reliable power source. By integrating solar panels, floor-cleaning robots can achieve longer operation times, reduced energy costs, and environmentally friendly performance.

Prototyping in Robot Development

Prototyping plays a critical role in designing effective robotic cleaners. Dam and Siang (2018) highlight a user-driven prototyping approach, where users create prototypes to better convey their needs and assumptions. Prototyping allows designers to test and communicate ideas about a system's form and functionality, providing essential feedback for iterative development and refinement.

Sensor Technologies

Ultrasonic and infrared sensors are widely employed in intelligent cleaning robots to enhance navigation and obstacle detection. In the study of Irawan et al. (2021), the ultrasonic sensor measures distances to detect obstacles, prompting the robot to change direction when necessary. The DC motor, controlled by a Motor Shield L298 and Arduino Uno microcontroller, powers the robot’s movement. It was also demonstrated that integrating ultrasonic and infrared sensor arrays with real-time environmental awareness significantly improves a cleaning robot’s navigation and route-planning capabilities. Electric-map-based grid-scanning algorithms further optimize coverage and efficiency, ensuring that the robot completes the cleaning task effectively.

Comparative Analysis

Table 1 presents a comparative analysis of the proposed solar-powered floor-cleaning robot against existing vacuum cleaner systems. Comparative analysis involves evaluating different systems to identify their similarities, differences, strengths, and limitations. In this study, the researchers compared their prototype with currently available vacuum cleaners to determine areas for improvement and to ensure that the proposed system offers additional value to users. This analysis also helps users understand the unique features and advantages of the proposed prototype.

The 3-in-1 Intelligent Sweeping Robot available in the market features one-button start, sweeping, mopping, vacuum cleaning, USB charging, universal driving, obstacle avoidance, anti-drop technology, low noise, low repetition, and high coverage. Once activated, it navigates across the floor, using intelligent sensors to avoid walls and obstacles, leaving dust and pet hair-free surfaces. However, it lacks an automatic charging station, so it turns off automatically when the battery is depleted.

Table 1

Comparative analysis

Description	Proposed Capstone Project	System 1 3-in-1 Intelligent Sweeping Robot	System 2 Upgrade High-Performance Robot Vacuum
Obstacle Detection	/	/	/
Automatic	/	/	/
Waste bin detection	/	x	x
Metal detection	/	x	x
Sanitize	/	x	/
Dry and wet	/	x	x
Sounds generated	/	x	x
Humidifier	x	x	/
USB Charging port	x	/	/
Ultra-thin	x	/	/
Power indicator	/	/	/
Anti-drop	x	/	/
Electric Charging	/	/	/
Solar Panel	/	x	x
Mobile Application	/	x	x
SMS Notification	/	x	x

The Upgrade High-Performance Robot Vacuum includes a comprehensive set of smart sensors, anti-collision and anti-drop mechanisms, strong suction power, and effective side brushes. It supports multiple cleaning modes, all-terrain detection, and a floating rolling brush, allowing it to adapt to various floor types. Additional features include a humidifier and UV disinfection, enhancing hygiene and cleaning efficiency.

Regarding solar-powered vacuum cleaners, Sukumaran (2022) proposed a practical method for developing a solar-powered, Bluetooth-enabled intelligent vacuum cleaner using an Arduino microcontroller. The system receives input from a Light Dependent Resistor (LDR) sensor and an ultrasonic sensor, which guides the vacuum's navigation. The battery can be recharged mechanically, and the device automatically recharges via a solar panel either after cleaning or when the battery level drops below a certain threshold. In addition, Irawan et al. (2021) used ultrasonic sensor, Motor Shield L298, Arduino Uno microcontroller, servo, and DC motor. The DC motor is powered by the Motor Shield L298, and the Arduino interprets data from the ultrasonic sensor to detect obstacles. The robot automatically changes direction when an obstacle is detected, ensuring uninterrupted cleaning. Finally, Sarmast et al. (2020), developed a vacuum cleaner that can be operated remotely via an Android smartphone or in autonomous mode. The system monitors battery voltage to prevent overcharging and notifies the user via text message when cleaning is complete. This dual-mode operation improves battery longevity, energy efficiency, and user convenience.

Through this comparative analysis, the proposed solar-powered floor-cleaning robot combines the best features of existing systems while integrating solar energy, autonomous navigation, and user-friendly operation, offering enhanced functionality and sustainability compared to current market alternatives.

Research Framework

Data

This study gathered data from the results of a survey conducted with seventy (70) respondents. The study used the ROA Soft formula to determine the total number of respondents and employed a random sampling method to distribute the questionnaires. The survey questions were based on the ISO 25010 standard, covering the following characteristics: usability, performance efficiency, functional suitability, reliability, portability, compatibility, and maintainability.

To gather responses, the study used a four-point Likert scale, allowing respondents to indicate their level of agreement with each statement. The scale included the categories: strongly agree, agree, disagree, and strongly disagree. Each category was assigned a corresponding mean range to facilitate clear and consistent interpretation of the survey results.

Table 2 presents the set of data used for creating the prototype. This data provides detailed descriptions of the various measurements considered during the prototype's development, including the width, range, and size of the materials. These specifications ensure that the prototype is accurately constructed, functions effectively, and meets the design requirements for optimal performance.

Table 2

Data set considered in creating a prototype

Data Set	Description	Unit of Measurement
Ultrasonic Sensors (Obstacle)	Weight	Gram
	Range	Centimeter
IR Sensor (Waste Bin)	Length	Centimeter
	Width	Centimeter
	Distance	Inches
Metal Sensor	Length	Inches
	Width	Inches
	Weight	Gram

Table 3

Dataset for creating the prototype

Data Set	Description	Unit of Measurement
Battery	Weight	Kilogram
	Length	Inches
	Width	Inches
	Operating Current	Voltage
Water Pump	Length	Inches
	Width	Inches
	Operating Current	Voltage
Vacuum	Weight	Kilogram
	Length	Inches
	Operating Current	Voltage
Servo Motor	Weight	Gram
	Operating Current	Voltage
PVC Pipe	Length	Inches
	Width	Inches
	Diameter	Area

Table 3 presents the set of data used for creating the prototype. The table includes details on the weight, size, and operating current of the materials considered. The researchers specifically examined the operating current of the materials to estimate the prototype's lifespan and ensure its durability and efficient performance.

Ethical Considerations

The study adhered to Republic Act No. 10173, also known as the Data Privacy Act, which aims to protect personally identifiable and sensitive information. This law applies to individuals and organizations that handle sensitive data.

To avoid ethical violations, the researchers ensured that participation in the study was entirely voluntary. Every participant provided informed consent, making voluntary participation a fundamental principle of research ethics.

Collecting personal information was an essential part of the study, and the researchers ensured the confidentiality of all participants and their responses. No data was shared with unauthorized individuals, except in cases where disclosure was legally required. As Pye (2009, p. 136) emphasizes, ethical decisions in research involve balancing the preservation of data for future use with the protection of participants' rights in the present.

Participants were informed of the study's objectives and were free to withdraw at any time during interviews or surveys. They also consented to the recording of their information and responses, with the assurance that participation would not result in any adverse consequences. Furthermore, all participants were informed that their data would remain confidential.

Experimental Design

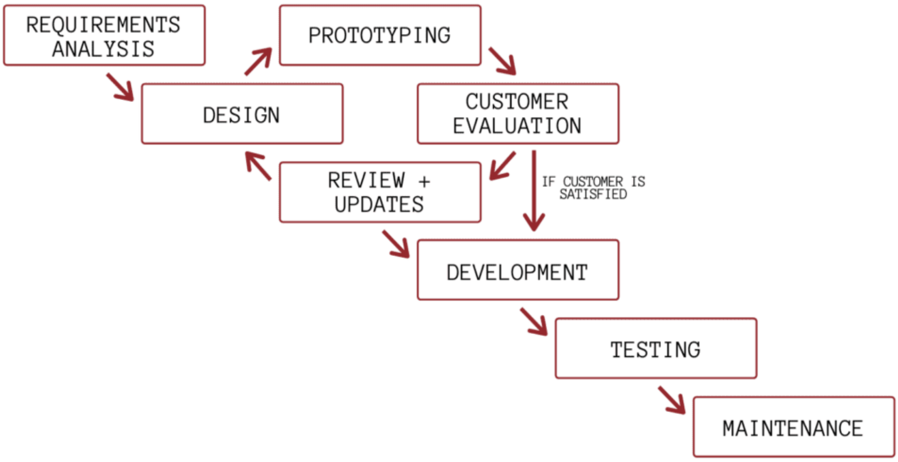
Various system development methodologies were designed and applied to achieve the system's objectives. In this study, the researchers employed a prototyping model. This approach involved building and testing a prototype before developing the final, fully functional version of the system. The prototyping model was particularly suitable in scenarios where not all project requirements were fully defined at the outset.

Procedures of the Different Phases

Figure 1 presents the prototyping model used for developing the prototype.

Figure 1

Prototyping model



The model followed an iterative process of creating and refining the system through multiple prototype iterations. The initial prototype served as a proof of concept, demonstrating the core features and functionalities of the system. Feedback and insights obtained from testing the initial prototype informed subsequent iterations, leading to improvements and enhancements that addressed identified issues. User requirements and feedback were continuously gathered and integrated throughout the design process. This iterative approach ensured flexibility and adaptability, resulting in a final prototype that effectively detected obstacles and incorporated other essential features. The model also enabled the integration and testing of various sensors and components to ensure accurate detection and reliable performance.

Requirements analysis. During this phase, the researchers collected and analyzed user expectations. The researchers conducted interviews with clients to better understand the system flow and document request process. They defined the problem, gathered relevant data from clients, and analyzed and determined the system's objectives and software requirements.

Design. Following requirements analysis, the researchers moved to the design phase. The design incorporated user suggestions, feedback, and identified system components to finalize the system. Team members collaborated continuously to study, develop, and innovate the project, ensuring optimal output.

Prototyping. The prototype served as a compact and operational model of the system, enabling evaluation and enhancement of design and functionality. During this stage, the researchers acquired essential components, including a microcontroller, sensors, jumper wires, and a GSM module, to construct a tangible prototype. Development was based on insights gathered from the preliminary design phase, allowing for practical testing and further improvements.

Customer evaluation. At this stage, the system was presented to the client for an initial evaluation. This process identified the strengths and weaknesses of the working model. Comments and suggestions were collected from the client and provided to the researchers for refinement. If the client was satisfied with the first prototype, the review and update phases were bypassed, proceeding directly to the development phase.

Review updates. If the client was not satisfied with the prototype, the researchers refined the system based on the feedback and suggestions provided. Adjustments were made to enhance functionality while ensuring all client recommendations were addressed.

Development. In the development phase, the researchers created the final working system or product, implementing the tasks it was designed to perform. After incorporating client requirements and requests, the system was constructed and tested to ensure it functioned correctly.

Testing. The system underwent comprehensive testing to verify correct functioning and identify potential issues. Researchers performed continuous troubleshooting and supported software development throughout this phase. Intensive checks were conducted to ensure error-free operation and compliance with necessary standards.

Maintenance. After testing, the prototype was implemented in the client environment or deployed for market use. Regular maintenance was planned to ensure that the robots operated effectively and efficiently, keeping the system functional and reliable over time.

Technical Framework

Materials

This section presents the software and hardware requirements in developing the system.

Software

The researchers utilized various software and tools to design and implement the system effectively. The Arduino Integrated Development Environment (IDE), a cross-platform application written in Java, was used to write and upload programs to the microcontroller. The Arduino IDE supports C and C++ programming languages with specific code structuring rules and provides a software library from the Wiring project, offering numerous standard input and output procedures. The C programming language was employed as a general-purpose, object-oriented, and imperative language, allowing for low-level memory manipulation and flexible system control. Additionally, the researchers used MIT App Inventor, an intuitive visual programming environment that enables the creation of fully functional smartphone and tablet applications, facilitating user interface design and remote system control.

Hardware

Table 4 outlines the planned hardware requirements for the system, detailing the materials and specifications needed to construct the prototype.

Table 4

Hardware Requirements

	Specifications
Arduino Mega 2560 	Microcontroller: ATmega2560 Operating Voltage: 5V Input Voltage(recommended):7-9V Input Voltage(limit):6-9V Digital I/O Pins: 54 (of which 15 provide PWM output) Input Pins:16
Arduino Uno 	Microcontroller Microchip ATmega328P Operating Voltage 5V USB Standard Type B Digital I/O Pins 14 PWM Digital I/O Pins 6 Analog Input Pins 6
MG996R 	Weight: 55g Dimension: 40.7×19.7×42.9mm Stall torque: 9.4kg/cm (4.8v); 11kg/cm (6.0v) Operating speed: 0.19sec/60degree (4.8v); 0.15sec/60degree (6.0v) Operating voltage: 4.8~ 6.6v
MG995 	Weight: 55g Dimension: 40.7×19.7×42.9mm Stall torque: 9.4kg/cm (4.8v); 11kg/cm (6v) Operating speed: 0.20sec/60degree (4.8v); 0.16sec/60degree (6.0v) Operating voltage: 4.8~ 6.6v

Vacuum Cleaner 	Item Length: 30cm Material Type: ABS Weight: 0.52kg Item Width: 10.5cm Size: 304x74x74mm Suction:4800PA
Bluetooth Module 	Bluetooth protocol: Bluetooth Specification v2.0+ EDR Frequency: 2.4GHz ISM band Modulation: GFSK (Gaussian Frequency Shift Keying) Speed: Asynchronous: 2.1Mbps (Max) / 160 kbps, Synchronous: 1Mbps/1Mbps
SIM800C GSM module 	Supports Quad-band 850/900/1800/1900 MHz, which can transmit voice calls, SMS messages, and low-power data. GPRS multi-slot class 12/10 Compatible with GSM 2/2 + Class 1 (1 W 1800 / 1900MHz) Bluetooth 3.0 + EDR compatibility FM: International band 76 ~ 109MHz, 50KHz correction level. Control over AT instruction set Voltage: 4.1 ~ 5VDC Operating Temperature: -40 ~ 85
IR Infrared Obstacle Avoidance 	Item size:32x14mm/1.26x0.55in Package size: 45x45x20mm/1.77x1.77x0.79in Package weight:8g
Metal detector 	LJC18A3-B-Z/BX/AY/BY/AX proximity sensor cylindrical capacitive proximity switch 10mm detection distance NPN/PNP NO/NC DC6-36V
Ultrasonic Sensor	Working Voltage: 5V DC

Detection Range: 2cm-450cm.

Weight: 10g

Size: 45mm x 21mm (L x W)

Connector Pin: VCC, Trig (T), Echo(R), OUT, GND

Mini Water Pump

Operating Current: 130 ~ 220mA

Flow Rate: 80 ~ 120 L/H

Maximum Lift: 40 ~ 110 mm

Outlet Outside Diameter: 7.5 mm

Outlet Inside Diameter: 5 mm

Battery

Brand Name: Jungla

Weight: 0.98kg

Size: 70x56x37 MM

Model: 3S2P

Nominal capacity: 12800mAh

Weight: 0.98kg

Size: 70X56X37 MM

Normal Capacity: 12800mAH

Battery standard: 18650 lithium battery

Internal resistance: 3c

DC Gear Motor and Wheels

Length: Approx. 67mm / 2.64inch

Wheel diameter: 65mm / 2.56inch

Shaft diameter: 4mm / 0.16inch

Voltage: DC 12V

Color: Silver

Solar Panel

Maximum Power: 25W

Weight: 2.05 kg

Dimension: 550x364x25

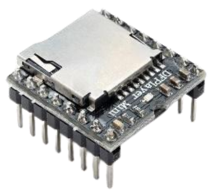
Max. Voltage: 600

Cell Technology; Monos

H-Bridge Driver

Chip: L298N (ST NEW)

Logical voltage: 5V

	Drive voltage: 5V-35V Logical current: 0mA-36mA Drive current: 2A (MAX single bridge) Max power: 25W
Arduino MP3 Module 	Supports sampling rates (KHz): 8 / 11.025 / 12/16 / 22.05 / 24/32 / 44.1 / 48 24-bit DAC output, dynamic range support: 90dB, SNR support: 85dB Fully supports FAT16, FAT32 file system, maximum support 32G TF card, support U disk to 32G, 64M bytes of NORFLASH
Limit Switch 	Micro Switch Hinge Roller Lever 15A V-156-1C25 Model: V-156-1C25 Rating:15A, 1/2HP, 125/250VAC 0.6A,125VDC; 0.3A, 250VDC
Relay Module 	Control Voltage: 5V DC Max Control Capacity:10A 250VAC or 10A 30VDC
PVC Pipe 	50.8mm 18x14 inch

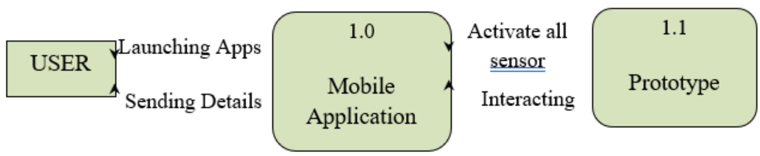
The researchers utilized a variety of hardware components, including sensors to detect obstacles and an Arduino microcontroller to process sensor data and make decisions. These components work together to ensure accurate detection, proper functioning, and reliable performance of the prototype. All specified materials were essential for the successful development and operation of the solar vacuum and floor-cleaning robot.

Modeling

Figure 2 presents the context diagram, illustrating the fundamental operation of the user-controlled prototype.

Figure 2

Context diagram of the developed system



The diagram shows that the user must first launch the mobile application to activate all sensors and power on the prototype. Once activated, the prototype communicates with the user by sending relevant information and updates through the application, ensuring real-time monitoring and control of the cleaning process.

Figure 3

Context diagram of the developed system

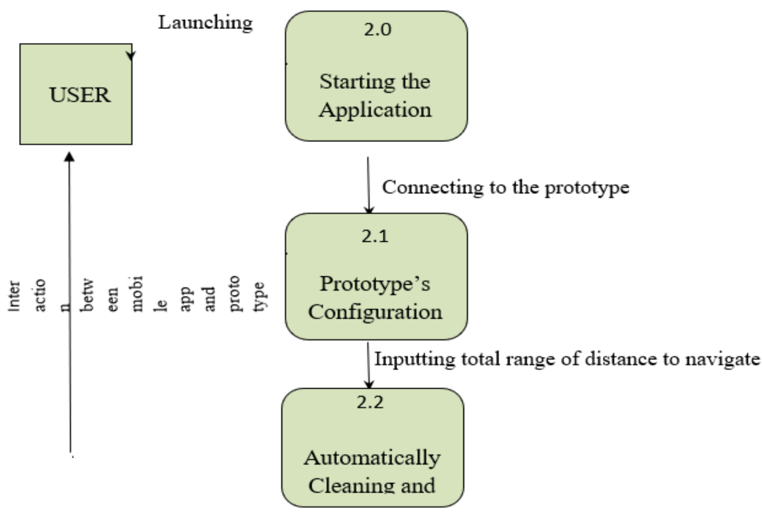


Figure 3 presents the context diagram of the developed system, illustrating the interaction between the user and the prototype. To operate the system, the user must first start the application and establish a direct connection with the prototype. The user then inputs the total range of distance for the cleaning operation. Once configured, the prototype autonomously vacuums dust and mops the floor. If the prototype detects any obstacles such as metal objects, a low battery, or a full dustbin, it communicates with the user by sending a notification via text message to the mobile phone, ensuring timely intervention and continuous operation.

Figure 4

Flowchart of the developed system

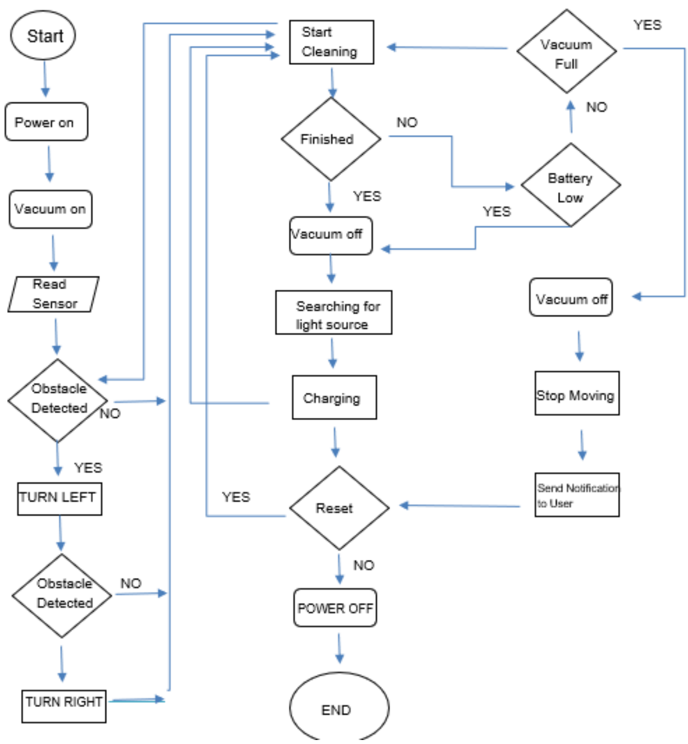


Figure 4 presents the flowchart of the developed prototype, illustrating the system's operational process. The procedure begins with the initialization of all sensors and modules to ensure proper connectivity. The program is activated through commands from the mobile application, which functions as the prototype's on/off control. The DC motor then initiates forward motion, and the ultrasonic sensor continuously monitors for obstacles. Upon detecting an obstacle, the device automatically reverses its route to avoid collisions. The system also incorporates SMS notifications to inform the user of critical conditions, such as a full dustbin or low battery. When the battery reaches a low level, the vacuum ceases cleaning and searches for a power outlet. The user can then recharge the device and power it off, ensuring safe and continuous operation.

Figure 5

Story board of the developed system

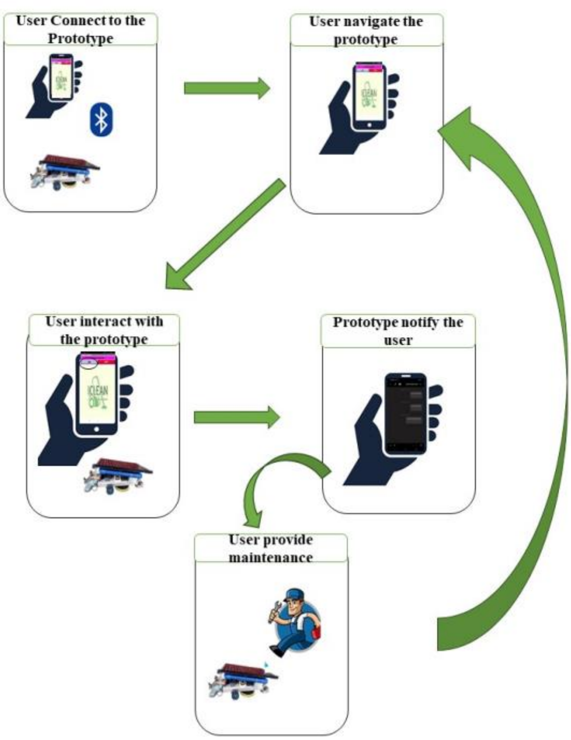


Figure 5 presents a visual guide illustrating the interaction between the user and the prototype throughout the operational process. The user first connects to the prototype via Bluetooth and ensures the device is ready for operation. Once activated, the prototype begins moving automatically, performing its cleaning tasks.

During operation, the prototype continuously monitors conditions such as the presence of metal, a full dustbin, or a low battery. When any of these conditions are detected, the system promptly notifies the user via text message. Finally, the user provides necessary maintenance to the prototype, ensuring its continued efficiency and proper functioning.

Figure 6

Prototype

Figure 6 shows the prototype. Using an Arduino microcontroller and various sensors, the system interprets ultrasonic signals as distance measurements. The cleaning robot automatically changes direction if an ultrasonic sensor detects an obstacle. When the sensor reads a distance of less than 5 cm, the robot adjusts its path to avoid collisions. According to Huang (2022), with the rapid advancement of AI theory, particularly deep learning neural networks, robot vacuums powered by AI can autonomously clean indoor floors using intelligent programming and automated vacuuming services.

The prototype is equipped with two batteries, each rated at 12,800 mAh, providing a combined capacity of 25,600 mAh. The total power consumption of the prototype is 10,400 mAh. Using a battery life calculator, which estimates operational time based on nominal battery capacity and device consumption, the estimated battery life was 2 hours and 27 minutes. Manual testing confirmed that a fully charged prototype could clean continuously for up to 2 hours. If the batteries were not fully charged, the prototype's operational time was reduced to approximately 30 minutes to 1 hour, demonstrating the practical endurance of the system under varying conditions.

Figure 7 shows the mobile app controlling the device. The study utilized MIT App Inventor to create a simple mobile application for controlling the vacuum cleaner. This web-based tool enabled seamless integration of the mobile application with the prototype via Bluetooth.

Figure 7

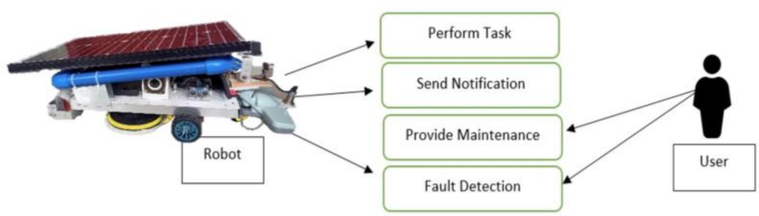
The mobile app

A Bluetooth-based Android interface was developed to control the robot effectively. Using MIT App Inventor, the researchers successfully built the application, which features a main screen with an On/Off button and a Bluetooth connection button that displays the connection status as either "Connected" or "Disconnected." During the initial stage, the Android application was developed using the Design and Block editors of MIT App Inventor, compiled, and then installed on an Android device. Communication between the Arduino microcontroller, responsible for controlling the robot, and the Android application was established via Bluetooth, allowing the user to operate the robot remotely.

Figure 8 presents the use-case diagram illustrating the interactions between the user and the prototype.

Figure 8

UML use case model between the user and the prototype



This diagram highlights the high-level functions and scope of the system, showing how the prototype performs its cleaning tasks while monitoring its environment. The prototype detects faults such as obstacles, a full dustbin, or low battery, and sends notifications to the user for appropriate action. Meanwhile, the user provides maintenance, monitors the prototype's performance, and addresses any detected defects, ensuring the system operates efficiently and reliably.

Figure 9

Circuit diagram of the prototype

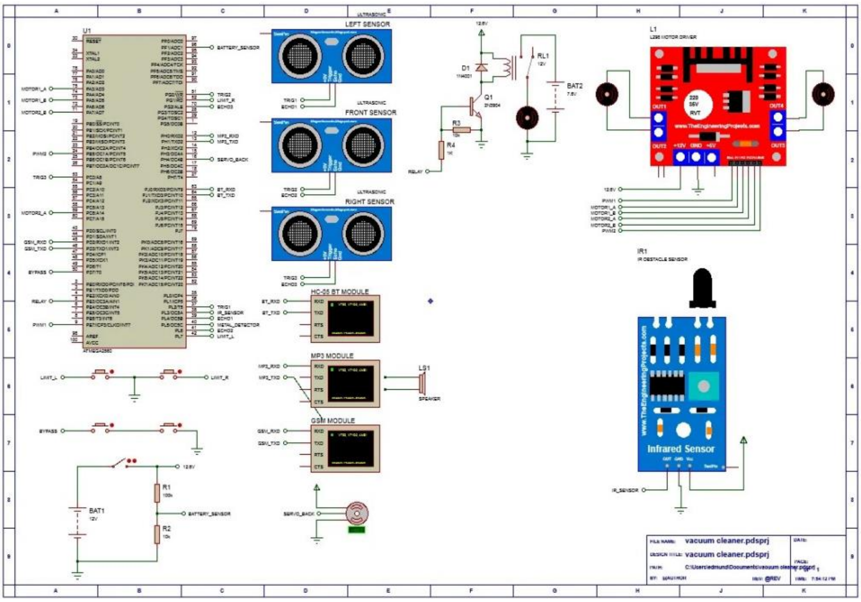


Figure 9 presents a pictorial circuit diagram, offering a visual representation of the prototype's electrical connections and overall architecture. This diagram is useful for planning, constructing, and maintaining the system. It illustrates the integration of key components, including three ultrasonic sensors, an infrared sensor, the HC-05 Bluetooth module, an MP3 module, and a GSM module, all connected to the Arduino board, which serves as the central control unit. The ultrasonic sensors handle obstacle detection, while the infrared sensor monitors the dustbin to prevent overloading. The HC-05 module enables Bluetooth connectivity, and the GSM module sends SMS notifications to inform the user of the prototype's status. By effectively integrating these components, the iClean prototype meets the functional and operational requirements for efficient autonomous floor cleaning.

Figure 10

Presents the system architecture of the prototype

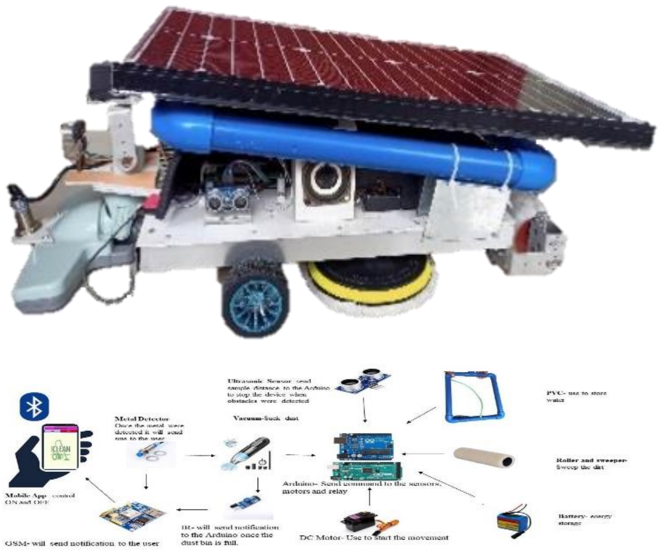


Figure 10 illustrates the process flow of the developed system. After completing the coding phase, the system begins by initializing all sensors and modules to establish a connected and ready state. Once initialized, the sensors start monitoring the environment based on the parameters set in the system. The Arduino microcontroller sends these specific parameters to the sensors to verify whether the conditions are met. The GSM module serves as a communication interface, notifying the user when the system detects metal obstacles, a full dustbin, or a low battery condition.

Table 5 presents the detailed breakdown of the materials, tools, and equipment used in developing the prototype, including their respective prices and the total project cost. This cost documentation is crucial as it provides transparency regarding the resources utilized and the financial requirements necessary to complete the system. It also allows future researchers, developers, or potential investors to clearly understand the financial considerations involved in replicating or improving the project.

Table 5

Cost and Benefits Analysis

Name	Unit Price	Quantity	Total
Arduino mega2560	₱ 900	1	₱ 900
Arduino Uno	₱ 590	1	₱ 590
MG996R	₱ 300	3	₱ 900
MG995	₱ 300	1	₱ 300
vacuum cleaner	₱ 1300	1	₱ 1300
Bluetooth module	₱ 275	1	₱ 275
SIM800C GSM module	₱ 700	1	₱ 700
IR through beam sensor	₱ 100	1	₱ 100
metal detector	₱ 800	1	₱ 800
ultrasonic sensor	₱ 100	3	₱ 300
mini water pump	₱ 300	1	₱ 300
18650 Battery 2S Charging Module Board	₱ 235	1	₱ 235
18650 Battery 3S Charging Module Board	₱ 235	1	₱ 235
DC geared motor	₱ 350	2	₱ 700
3S-2P 12V 12800mAh battery	₱ 750	2	₱ 1500
65mm Rubber Tire	₱ 150	2	₱ 300
25W solar panel	₱ 1025	1	₱ 2500
L298 H bridge driver	₱ 100	1	₱ 100
Arduino mp3 module	₱ 200	1	₱ 200
Limit switch	₱ 60	2	₱ 120
Relay module	₱ 150	1	₱ 150
Misc	₱ 3000	1	₱ 3000
TOTAL			**₱ 15,505**

To determine the project’s economic feasibility, the researchers performed a cost-benefit analysis by summing up all incurred expenses and comparing them with the anticipated advantages of the system. This evaluation is an essential part of project development as it establishes whether the benefits gained will outweigh the costs invested. By doing so, the researchers ensured that resources were allocated effectively, minimizing unnecessary expenditures while maximizing potential returns.

The analysis further highlighted the practicality of implementing the "I Clean: A Prototype Solar Vacuum and Floor Cleaner Robot" as a viable solution for household cleaning. Since the system is powered by solar energy, it offers long-term savings by reducing electricity consumption compared to traditional vacuum cleaners. Additionally, its multifunctional cleaning features present added value to users by combining vacuuming and floor cleaning in one device, which reduces the need to purchase multiple cleaning tools. These advantages demonstrate not only convenience and efficiency but also sustainability and cost-effectiveness.

Evaluation of the System

This section presents the results of a survey conducted with seventy (70) respondents. The survey questions were based on ISO 25010 standards, covering key system characteristics such as usability, performance efficiency, functional suitability, reliability, portability, compatibility, and maintainability.

Table 6

Weighted mean distribution of the criteria of the proposed system

Criteria	Weighted Mean	Remarks
Functional Suitability	3.49	Strongly Agree
Performance Efficiency	3.58	Strongly Agree
Compatibility	3.53	Strongly Agree
Usability	3.53	Strongly Agree
Reliability	3.55	Strongly Agree
Maintainability	3.53	Strongly Agree
Portability	3.64	Strongly Agree
Average	**3.55**	**Strongly Agree**

Table 6 presents the weighted mean results of each quality characteristic based on ISO 25010, gathered from 70 respondents. The overall system evaluation obtained an average weighted mean of 3.55, which corresponds to Strongly Agree. According to ISO 25010, the software quality model evaluates systems across several dimensions: usability, performance efficiency, functional suitability, portability, compatibility, reliability, and maintainability. The results suggest that the proposed system is ready for operation and capable of performing the specified requirements.

Functional suitability. The system achieved an average weighted mean of 3.49, interpreted as Strongly Agree. This indicates that the prototype effectively fulfills its intended purpose, automating traditional cleaning tasks such as dusting and sweeping floors. It performs the designated actions accurately, achieving the desired results by automatically cleaning with the required precision. This demonstrates the system's capability to provide the intended functionality.

Performance efficiency. The prototype scored an average weighted mean of 3.58, also interpreted as Strongly Agree. This was the highest rating among the categories, highlighting the system's ability to produce the intended results with minimal waste of time, effort, and resources. In terms of time behavior and resource utilization, the system performed efficiently and met the expected requirements.

Compatibility. With an average weighted mean of 3.53, the system was rated Strongly Agree in terms of compatibility. This reflects the prototype's ability to exchange information and perform required functions while operating within a shared hardware or software environment. It demonstrates that the system can operate effectively alongside other products without negative impact.

Usability. The system also achieved an average weighted mean of 3.53, interpreted as Strongly Agree. This indicates that the prototype is user-friendly, allowing users to easily determine whether the product meets their needs, particularly useful for busy individuals. Moreover, the inclusion of solar charging enhances usability during emergencies. Overall, the system is both effective and enjoyable for users.

Reliability. The prototype obtained an average weighted mean of 3.55, with a remark of Strongly Agree. This suggests that the system operates reliably under normal conditions. It remains functional and accessible when needed and is capable of restoring its original condition after interruptions or failures. This demonstrates the robustness of the system against operational challenges.

Maintainability. The maintainability rating, with an average weighted mean of 3.53, was also interpreted as Strongly Agree. This indicates that the system components can be adjusted independently without negatively affecting performance. The prototype can be modified or updated efficiently, ensuring sustainability over time.

Portability. The highest weighted mean was recorded under portability, with a score of 3.64, also corresponding to Strongly Agree. This demonstrates that the prototype is portable, easy to install and uninstall, and adaptable for replacement with other specified software serving similar functions. Its design enables operational flexibility and efficient adaptation to evolving requirements.

Economic feasibility. Economic feasibility assesses whether the anticipated benefits of the system are equal to or greater than its projected costs. To determine this, a cost-benefit analysis was performed. This analysis provided insights into both the advantages and limitations of the system, offering a clearer comparison between costs and benefits. The ISO 25010 questionnaire-based system assessment further validated that the prototype functions correctly and delivers value, thereby supporting its economic feasibility.

Technological feasibility. Feedback gathered after the successful completion of the project highlighted the innovative nature of the prototype. Respondents emphasized that the construction of the system represents a unique technological advancement that benefits its users. As technology continues to progress, the development of an automatic cleaning robot contributes to everyday convenience, particularly for busy individuals. Overall, comments from respondents consistently recognized the prototype as an excellent technological achievement.

Operational feasibility. The prototype is operationally feasible, as users can operate it with ease and minimal instruction. Survey results showed that it took only a few minutes of demonstration before users were able to control the robot independently. The system requires a simple on-and-off mechanism to activate movement and cleaning, and users can conveniently connect it via Bluetooth to initiate operations. These findings demonstrate the practicality and usability of the prototype in real-world settings.

Conclusion

The study demonstrated that the design and construction of the prototype significantly enhanced traditional cleaning methods such as dusting and sweeping. The system was able to automatically detect obstacles and collect dust through the integration of components such as the Arduino microcontroller and ultrasonic sensors, which enabled it to interpret distance and adjust movement accordingly. Furthermore, the researchers successfully integrated the prototype with a mobile application installed on an Android device, allowing users to control the robot through Bluetooth communication with the Arduino microcontroller. This seamless integration between hardware and software proved the system's capability for efficient and convenient remote operation. Testing also revealed that the prototype could operate for one to two hours on a single charge, requiring approximately two hours of charging using electricity and four to five hours using solar panels. This dual charging feature, along with extended battery life, provides a clear advantage over many conventional vacuum cleaners available in the market. In addition, the evaluation of the system using ISO 25010 standards confirmed that the prototype met and, in several areas, exceeded the quality requirements in terms of functional suitability, performance efficiency, compatibility, usability, reliability, maintainability, and portability. These high ratings affirm that the system functions as expected, offering an efficient and effective cleaning solution.

Bibliography

Adeyoyin, S. O., Alawiye, M. K., & Ewulo, O. R. (2019). Awareness and use of solar energy as alternative power source for ICT facilities in Nigerian university libraries and information centres. *Library Philosophy and Practice (e-journal),* 2372. https://digitalcommons.unl.edu/libphilprac/2372

Babashahi, L., Barbosa, C. E., Lima, Y., Lyra, A., Salazar, H., Argôlo, M., Almeida, M. A. d., & Souza, J. M. d. (2024). AI in the workplace: A systematic review of skill transformation in the industry. *Administrative Sciences, 14*(6), 127. https://doi.org/10.3390/admsci14060127

Chuang, S., Shahhosseini, M., Javaid, M., & Wang, G. G. (2024). Machine learning and AI technology-induced skill gaps and opportunities for continuous development of middle-skilled employees. *Journal of Work-Applied Management.* Advance online publication. https://doi.org/10.1108/JWAM-08-2024-0111

Chuang, Y.-T., Chiang, H.-L., & Lin, A.-P. (2025). Insights from the Job Demands–Resources model: AI's dual impact on employees' work and life well-being. *International Journal of Information Management, 83*, 102887. https://doi.org/10.1016/j.ijinfomgt.2025.102887

Dam, R., & Siang, T. (2018). *Prototyping: Learn eight common methods and best practices.* Interaction Design Foundation. https://edtechbooks.org/-SZt

Diawati, P., Gadzali, S. S., Abd Aziz, M. K. N., Almaududi Ausat, A. M., & Suherlan, S. (2023). The role of information technology in improving the efficiency and productivity of human resources in the workplace. *Jurnal Teknologi Dan Sistem Informasi Bisnis, 5*(3), 296–302. https://doi.org/10.47233/jteksis.v5i3.872

Expert Market Research. (n.d.). *Philippines vacuum cleaner market: Size, share, trends, analysis, report 2024–2032.* Retrieved October 6, 2025, from https://www.expertmarketresearch.com/reports/philippines-vacuum-cleaner-market

Georgieff, A., & Hyee, R. (2022). Artificial intelligence and employment: New cross-country evidence. *Frontiers in Artificial Intelligence, 5*, 832736. https://doi.org/10.3389/frai.2022.832736

Jain, M., Rawat, P. S., & Morbale, J. (2017). Automatic floor cleaner. *International Research Journal of Engineering and Technology (IRJET), 4*(4).

https://d1wqtxts1xzle7.cloudfront.net/53485636/IRJET-V4I461
John, J. S., Dash, S. M., Sharma, A., Kashyap, A., & Yadav, V. (2022). Design and analysis of solar-powered automated lawn mower with vacuum cleaner. In *Proceedings of the 2022 International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI)* (pp. 1–5). IEEE. https://doi.org/10.1109/ACCAI53970.2022.9752583
Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K.-H. (2018). Solar energy: Potential and future prospects. *Renewable and Sustainable Energy Reviews, 82*(Part 1), 894–900. https://doi.org/10.1016/j.rser.2017.09.094
Kassa, B. Y., & Worku, E. K. (2025). The impact of artificial intelligence on organizational performance: The mediating role of employee productivity. *Journal of Open Innovation: Technology, Market, and Complexity, 11*(1), 100474. https://doi.org/10.1016/j.joitmc.2025.100474
Liu, W., Chen, J., Fei, Y., Hu, Z., Yu, C., & Gao, W. (2024). A design study on commercial cleaning robots based on Kano–QFD. *Sustainability, 16*(20), 8935. https://doi.org/10.3390/su16208935
Liu, X., & Li, Y. (2025). Examining the double-edged sword effect of AI usage on work engagement: The moderating role of core task characteristics substitution. *Behavioral Sciences, 15*(2), 206. https://doi.org/10.3390/bs15020206
Liu, Z., Liang, X., Chen, X., & Wen, X. (2024). Design of a sweeping robot based on fuzzy QFD and ARIZ algorithms. *Heliyon, 10*(19), e38319. https://doi.org/10.1016/j.heliyon.2024.e38319
Malobický, B., Hruboš, M., Kafková, J., Krško, J., Michálik, M., Pirník, R., & Kuchár, P. (2025). Towards seamless human–robot interaction: Integrating computer vision for tool handover and gesture-based control. *Applied Sciences, 15*(7), 3575. https://doi.org/10.3390/app15073575
Muthugala, M. A. V. J., Vengadesh, A., Wu, X., Elara, M. R., Iwase, M., Sun, L., & Hao, J. (2020). Expressing attention requirement of a floor cleaning robot through interactive lights. *Automation in Construction, 110*, 103015. https://doi.org/10.1016/j.autcon.2019.103015
Nicholls, L., & Strengers, Y. (2019). Robotic vacuum cleaners save energy? Raising cleanliness conventions and energy demand in Australian households with smart home technologies. *Energy Research & Social Science, 50*, 73–81. https://doi.org/10.1016/j.erss.2018.11.019
Nurjaya, N., Affandi, A., Erlangga, H., Sunarsi, D., & Jasmani, J. (2021). The

effect of product promotion and innovation activities on marketing performance in middle small micro enterprises in Cianjur. *Budapest International Research and Critics Institute (BIRCI) Journal, 4*(1), 819–826. https://doi.org/10.33258/birci.v4i1.1636

Ra, S., Shrestha, U., Khatiwada, S., Yoon, S. W., & Kwon, K. (2019). The rise of technology and impact on skills. *International Journal of Training Research, 17*(sup1), 26–40. https://doi.org/10.1080/14480220.2019.1629727

Rasool, T., Warraich, N. F., & Sajid, M. (2022). Examining the impact of technology overload at the workplace: A systematic review. *Sage Open, 12*(3). https://doi.org/10.1177/21582440221114320

Sarmast, T. S. A., Pourseif, T., Esmaeil Nezhad, R., Mohajeri, M., Mohammadi, S., & Vaezi, A. (2020). Designing a smart vacuum cleaner in two modes of remote and automatic. *International Research Journal of Engineering and Technology (IRJET), 7*(7), 5291–5298.

Sukumaran, A., 3ZWbNS, & Musallami, S. A. R. (2022). A smart solar powered vacuum cleaner: Solar powered vacuum cleaner. *Journal of Student Research.* https://www.jsr.org/index.php/path/article/view/1520

Takayama, L., Ju, W., & Nass, C. (2008, March 12). Beyond dirty, dangerous and dull: What everyday people think robots should do. In *Proceedings of the 3rd ACM/IEEE International Conference on Human-Robot Interaction* (pp. 25–32). ACM. https://doi.org/10.1145/1349822.1349827

Venugopal, M., Madhavan, V., Prasad, R., & Raman, R. (2024). Transformative AI in human resource management: Enhancing workforce planning with topic modeling. *Cogent Business & Management, 11*(1). https://doi.org/10.1080/23311975.2024.2432550

Wang, X., Chen, M., & Chen, N. (2024). How artificial intelligence affects the labour force employment structure from the perspective of industrial structure optimisation. *Heliyon, 10*(5), e26686. https://doi.org/10.1016/j.heliyon.2024.e26686

Yatmono, S., Khairudin, M., Pramono, H. S., & Asmara, A. (2020). Development of intelligent floor cleaning robot. *Journal of Physics: Conference Series, 1413*(1), 012014. https://doi.org/10.1088/1742-6596/1413/1/012014

You, K., Zhou, C., Ding, L., & Wang, Y. (2025). Construction robotics in extreme environments: From Earth to space. *Engineering.* Advance online publication. https://doi.org/10.1016/j.eng.2024.11.037