Smart and Autonomous Cleaning Robot

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Abstract - In this era of modernisation, Automation and Human Machine Interaction (HMI) have become the need of the hour. Imagination has become more important than knowledge. Cleaning systems like vacuum cleaners are effective, but still require the presence of a human being to direct its function. These challenges have led us to the idea of developing a smart and advanced autonomous cleaning robot that provides cleanliness and sanitation without the need of any human intervention to the system. The most significant features of the robot include an air filtration mechanism, autonomous cleaning using obstacle avoidance, determining dark spots using image processing, self-docking etc. The bot can be remotely controlled using IOT applications or a mobile phone which can turn it ON/OFF, control blower speed etc. The robot is also capable of traversing to the charging station autonomously when battery potential reaches below a certain value. It can also be called to a specific location for cleaning using the mobile phone GPS. All these features integrated together prove to be a complete solution towards autonomy.

Index Terms - Autonomous, Cleaning, IOT, Image Processing, Sensors

I. INTRODUCTION

Every enclosed environment is usually prone to dust and dirt for example in home, offices, etc. The accumulation of dust and dirt may lead to many diseases and infections to the occupants. Automatic floor cleaners are thereby introduced in order to remove these dust particles efficiently with less human effort.

Jones, Joseph L. [1] developed a robot comprising of a self-adjusting cleaning head that includes an adjacent and independent vacuum assembly to optimize cleaning capability and minimizing power requirements. Hofner, Christian, and Günther Schmidt[2] created a mobile robot to perform floor cleaning while providing a planned path for maximum feasibility. The robot updates the path if any obstacles are encountered using motion patterns of the robot.

Ziegler, Andrew, et al.[3] developed an Autonomous bot to clean dry and wet elements on the floor. The first cleaning zone provides suction to lose particulates and the second zone collects the cleaning fluid from the floor. The chassis contains the cleaning fluid and a container for the collected waste. Haegermarck and Anders[4] created an object sensing system for robots to achieve autonomy. The obstacle sensing system is attached in both front and rear of the bot, which are in a neutral relationship. The bot maneuvers around the obstacle when it is detected. Bartsch, Eric Richard, et al.[5] have developed an autonomous bot using processing units for manipulating data. A horizontal surface with boundaries has been created to move autonomously. Sukkarieh, Salah et al.[7] have worked on the integration of GPS(Global Positioning System) and an IMU(Inertial Measurement Unit) to achieve autonomous traversal for mobile robots. It focusses on misalignments and errors received from the sensor system, corrects for values and integrates it for the final output. . Leabman et al.[8] have created Wireless charging pads for power and charging electronic devices. It comprises of a receiver connected to the antenna which receives pockets of energy. The invention focusses on mobility and ease in mounting on vehicles and similar systems. Jain, Sarthak et al. have worked on a basic home automation system using Raspberry Pi. They achieved remote networking with devices which enabled control through any Wi-Fi enabled device. Programming was done in Python language and switching action was shown. Borenstein, Johann, and Yoram developed a robot to avoid collision with obstacles using Ultrasonic sensors for detection and mapping. An algorithm was developed which was used to govern this robot to achieve its purpose.

After referring to previously done research, our approach takes the next step in the field. The floor cleaner is programmed in such a way that it can move freely and clean the area by vacuuming process. A wake-up call may be issued based on the user's requirements. IR sensors are used to detect the obstacles in its path and decide its path accordingly. Image processing on RaspberryPi detects the dark and dirty spots on the floor and a special algorithm is designed for them. A feature that has been incorporated with this device is the introduction of air filtering in a vacuum cleaner. The bot can also be controlled using an application on any Wi-Fi enabled smartphone. This package can widely be used for the purpose of increasing comfort level by reducing human effort and the time consumed in cleaning and maintenance.

II. DEVELOPMENT PROCESS

To achieve the target of developing such a robot with various subsystems on-board, we chose to follow the following procedure:
1. Identify the Problem
2. Survey Existing Solutions
3. Design improved solution(Robot)
4. Select appropriate components for optimum performance.
5. Integration and Assembly of whole system
6. Testing and Debugging

III. EXISTING SOLUTIONS

Considering the present enclosures such as home, office workspace, industrial chambers, one common key point we can infer is that floor cleaners are manually switched on when the occupant needs to clean the enclosure. Furthermore, the user must check for its battery condition after some duration of time again and again and when it is low, he/she has to manually change the battery or has to plug it into a socket for charging if the battery is rechargeable. Present floor cleaners often do not clean the dark spots in the area properly and in fact some part of that dark spot is left behind. Autonomous cleaning bots do exist in today's time but do not pack such useful features in the same package.

IV. SUBSYSTEM CLASSIFICATION AND COMPONENT SELECTION

1. Drive System- 2, 12V DC Geared Motors providing 4kg-cm torque at 250RPM. Pololu Dual Motor Driver.
2. Power System- 3-cell Li-Po battery, Vpeak-12.6V, Buck Converter
3. Microcontroller- Raspberry Pi 3
4. Sensors – Infrared Sensor, Logitech C270 Digital Camera, GPS Module U-Blox Neo-6M, Voltage Sensor
5. Vacuum System – 12VDC Hand vacuum cleaner.

V. DESIGN ARCHITECHTURE

All the components selected have to be meshed and integrated together for them to work as intended. The following design is made to ensure simplicity and efficiency in the system.

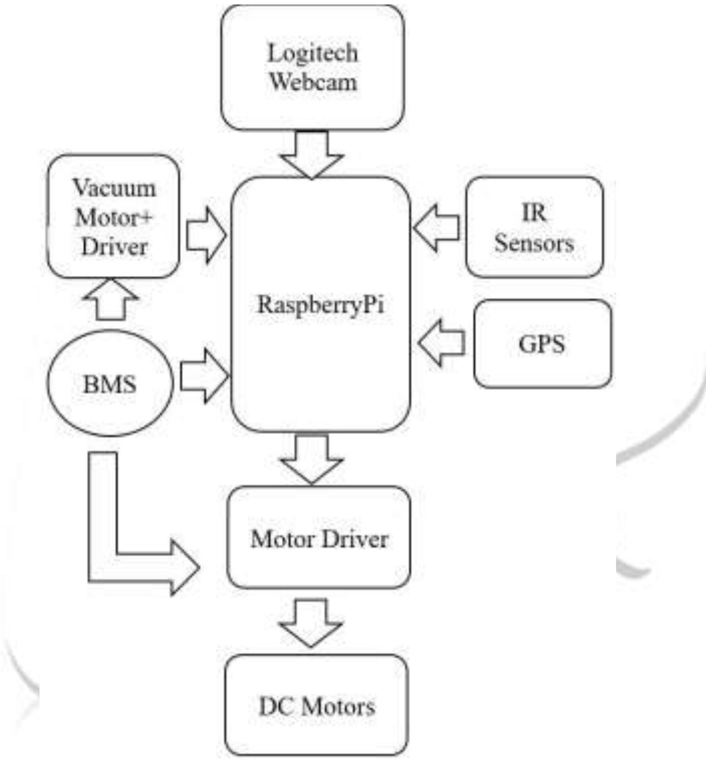

Fig.1 System Architecture of the Robot

The system is designed keeping the RaspberryPi as the main control unit. The module serves as a hub for all processing and data acquisition.

Module Functions: GPS co-ordinate data is fed to the RaspberryPi. The module uses GPS data to know current location and traverse to a given GPS co-ordinate using developed algorithms. The IR sensor is connected to provide data for on-coming objects. The bot stops and turns when an object is encountered in front. The RaspberryPi sends PWM(Pulse Width modulation) signals to the motor drivers to govern speed and direction of the motors. The Battery along with the buck converter provides power to the entire system according to their required voltages. The webcam provides image data to the processor. The image is processed, and dark spots are determined. When a dark spot is encountered the processor commands the motor driver to spend more time on the specific area for deeper cleaning.

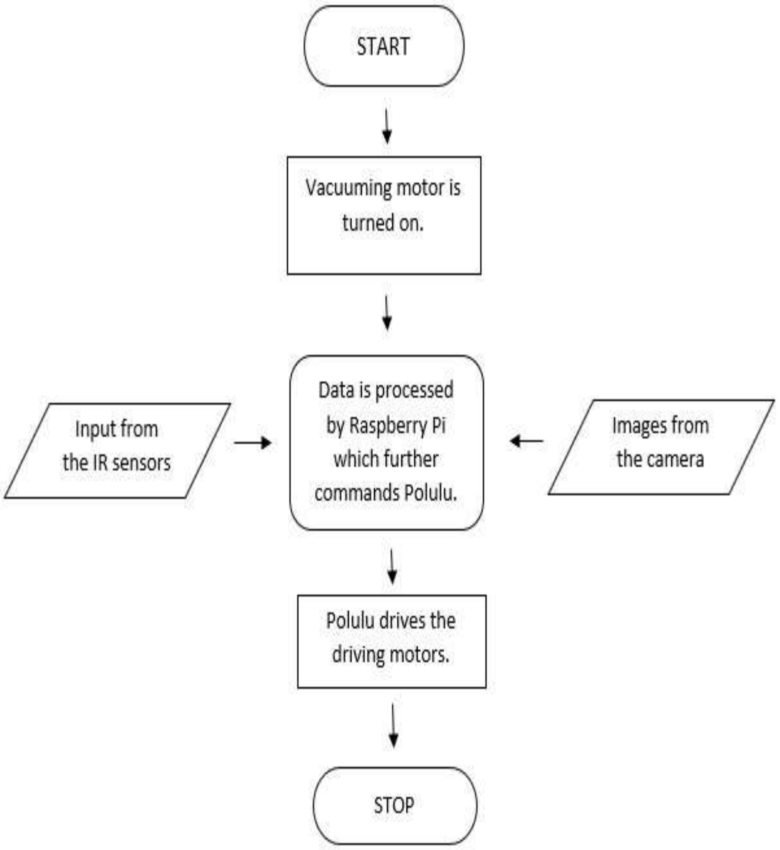

Fig2. System Base Algorithm

VI. POWER REQUIREMENTS

Component	**Voltage(V)**	**Current(A)**	**Current at 12V**
Motors	12V	1.2*2=2.4A	2.4A
Vacuum Motor	12V	5A	5A
RaspberryPi3	5V	3A	3*5/12= 1.25A
Sensors(All)	5V	0.1A	0.04A
Digital Camera	5V	1A	0.41A

Total Current : 2.4+5+1.25+0.04+0.41=**9.1A**
Battery: 12V,4.5Ah Li-Po.
Battery Run-Time=4.5/9.1=**0.49h=29.6min**

VI. SUBSYSTEM FUNCTIONS AND FEATURES

VI.I Air Filtration – The filtration of air is one of the key features of this robot. Air filtration must include the filtration of microparticles suspended in the air which can pose a serious threat to the environment and human health.

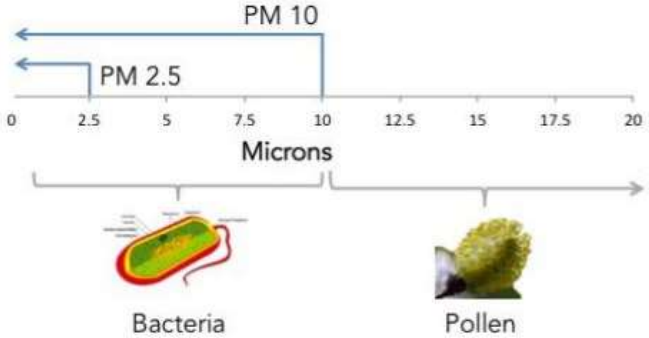

Fig.2 Particle Size Classification[11]

These microparticles can range from 10 micrometers (Coarse dust particles (PM10) are 2.5 to 10 micrometers in diameter. Sources include crushing or grinding operations and dust stirred up by vehicles on roads) to less than 2 micrometers (Fine particles (PM2.5) are 2.5 micrometers in diameter or smaller, and are produced from all types of combustion, including motor vehicles, power plants, residential wood burning, forest fires, agricultural burning, and some industrial processes). Fine particles also include pathogens such as certain bacteria which can cause deadly diseases. A three-layered filter apparatus can be employed to eliminate such microparticles.

Fig.3 Particle Filter Layer[12]

1. The first layer of pre-filter contains small pores with high retention rates for particles between 2-10 micrometers in size
2. The next activated carbon layer is used to filter out gasses, odor molecules, volatile organic compounds, chemical vapors, cigarette, pet, and/or flatulence odors. The activated carbon works based on the principle of chemical adsorption.
3. HEPA filters are composed of a mat of randomly arranged fibers The fibers are typically composed of fiberglass and possess diameters between 0.5 and 2.0 micrometers. The air space between HEPA filter fibers is typically much greater than 0.3 μm. The common assumption that a HEPA filter acts like a sieve where particles smaller than the largest opening can pass through is incorrect and impractical. Unlike membrane filters at this pore size, where particles as wide as the largest opening or distance between fibers cannot pass in between them at all, HEPA filters are designed to target much smaller pollutants and particles.

These particles are trapped (they stick to a fiber) through a combination of the following four mechanisms:

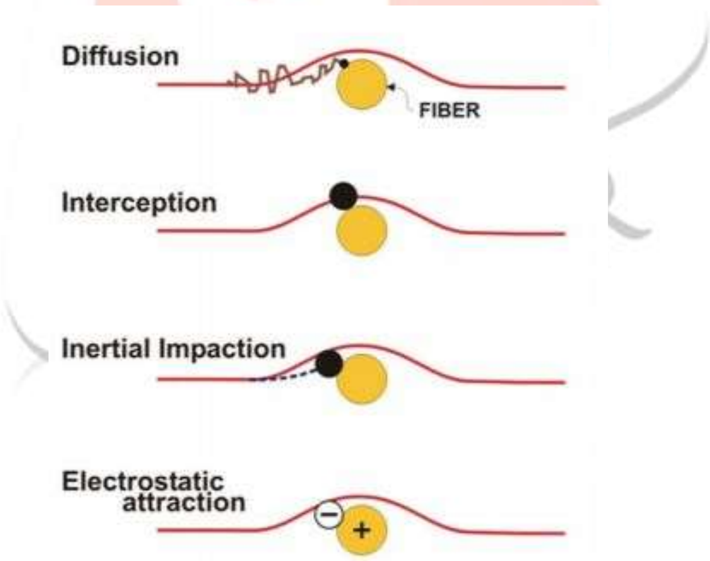

Fig.4 Filtration Mechanisms[13]

In addition to these filters , an ionizer can also be installed. Air ionizers are used to remove particles from air. Airborne particles become charged as they attract charged ions from the ionizer by electrostatic attraction. The particles in turn are then attracted to any nearby earthed conductors.

VI.II Patch Detection

A small single board computer, in this case the RaspberryPi 3 connected to a digital USB camera would be suitable for the detection of stains on the floor. The program uses the HSV color model (Hue, Saturation, Value) and finds the respective HSV Values for the floor. After that, the floor is filtered out of the image, by removing all areas of the image/video feed where the HSV values fall into the same range as that of the floor. Stains that are visually distinct from the floor are visible as they do not fall into that particular range. If the size of these "stains" is greater than the specified threshold value, it is marked as a stain and the location of the stain relative to the bot is found. Co-ordinates of the bot are recorded an cleaning is to be done more thoroughly in the specified spot. The bot then takes required actions based on whether there is a stain, and if so, the relative position of the stain. OpenCV is a Library which is made for real-time computer vision, and provides programming functions to help with the same. It has extensive support for C++, C, Python, Java and MATLAB/OCTAVE, though it has wrappers available for many other languages. It also supports a wide range of operating systems.

VI.III Self Docking

The self-docking feature of this robot is used to direct the it to its charging station using GPS co-ordinates. A GPS module(Neo-6M) mounted on the robot is used to record co-ordinates of the system. First, initial co-ordinates of the station are recorded, so that the robot can return to this specified location for charging.

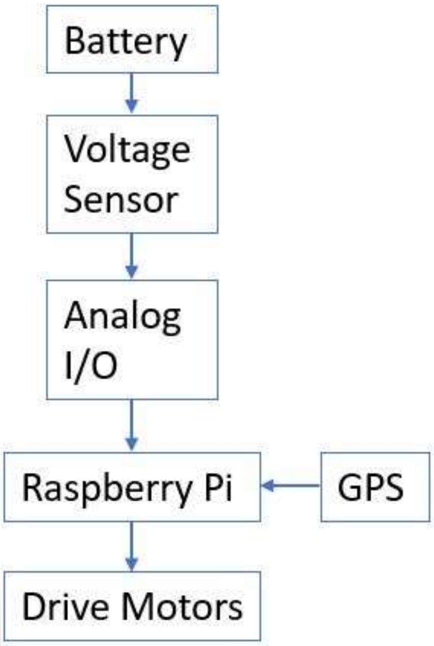

Fig.5 Self Docking Mechanism

When battery terminal voltage falls below 11.5V in a 3-cell battery, the voltage sensor sends a signal to the RaspberryPi. GPS co-ordinates of the last cleaning point is recorded. The bot is then directed towards the GPS co-ordinates of the charging station, where the robot is docked. Using Qi-wireless charging technology the bot is charged.

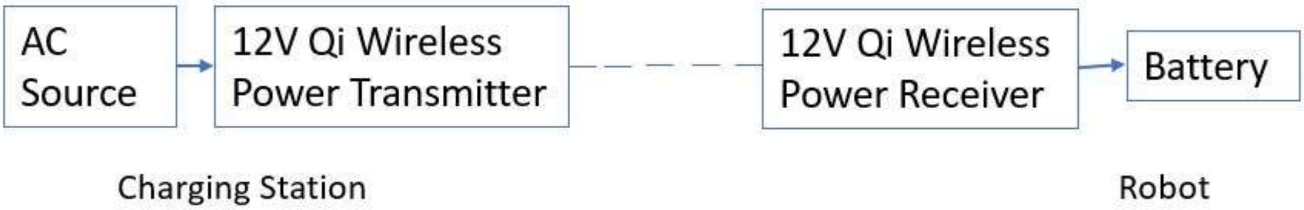

Fig.6 Wireless Charging

A 12V power transmitter is attached to and AC source which transmits power using the pad. The receiver is attached under the chassis, which is connected to the battery for charging. When the battery is fully charged, the bot is directed to the previous cleaning location, for it to resume the work.

VI.IV Control using Wi-Fi

The bot can be controlled using an application using the Wi-Fi module in the RaspberryPi. All bot data is transmitted to the smartphone and back, which provides an easy control solution for the robot in closed spaces.

VI.V Wake-Up Call

An internal clock is maintained by the cleaner. This allows it to be programmed to wake up at a particular time or it could be used to run the system for a certain period of time. The bot performs the cleaning operation in the designated area When the allotted time is finished, the cleaner uses the on-board to get back to the docking station.

VI. TESTING AND RESULTS

All the features of this robot were tested in an indoor environment to determine its performance and identify any possible bugs.

Fig.7 Final Prototype

IR sensors were incorporated in the robot to avoid any obstacles in the way and avoid them. 3 IR sensors were placed strategically to provide a greater angle of detection(120 degree).

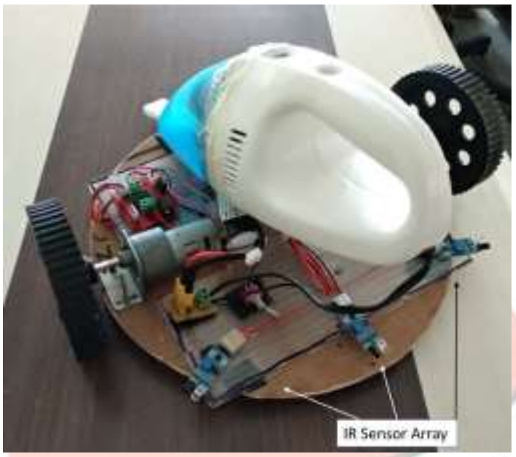

Fig.8 IR Sensor System

Patch detection algorithms were tested on the RaspberryPi using the Logitech C270 camera. Image Processing was done using OpenCV.

Fig.9 Spot Detection on the Floor(1)

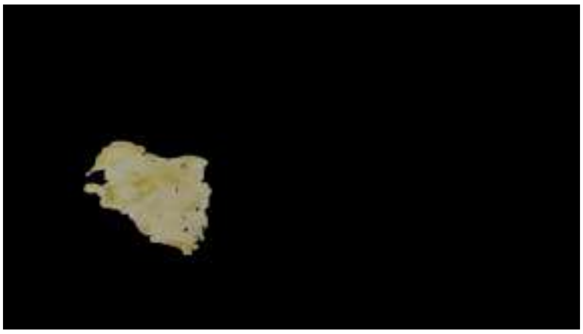

Fig.10 Spot Detection on the Floor(2)

The robot was successfully controlled using Blynk[14] application on the Android platform. Features including On/Off, Vacuum Suction level, Battery Voltage was controlled and monitored.

Fig.11 Control using Blynk application

All intended functions of the robot were tested successfully, and all tasks were completed.

XI.APPLICATIONS AND SCOPE

The developed robot can be used in various areas. Mainly, the robot is intended to be used in closed spaces like Offices, Homes, Factory floors, Classrooms, Buildings etc. It serves as an efficient solution for dry cleaning in such spaces.

The robot has a scope in wide and public spaces like Airports, Railway Stations, College campuses etc.

With a few modifications and further research in the system, this Autonomous robot can be used in such wide applications.

XII. ACKNOWLEDGMENT

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