RECENT PATENTS ON FLOOR CLEANING ROBOT APPLICATIONS AND NEW DEVELOPMENT PROSPECTS IN FUTURE

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ABSTRACT

Floor cleaning is considered by many to be one of the most boring and tiring routine household tasks. It is also one of the most promising personal robot applications. Autonomous floor cleaning robots are getting more popular for busy and aging populations. The purpose of this paper is to review the recent patents of a floor-cleaning robot based on US granted patents. An overview of fundamental floor-cleaning robots, typical patents and their patents contents are presented. Some enabling technologies which use to control the devices more capable are also patented. Some patents have now been commercialized are available for floor cleaning will be described. The significance of this paper lines in the presentation of a service robot of everyday tools for mankind, a cleaning robot in home.

KEYWORDS: Floor cleaning robot, Robot cleaner, Autonomous coverage robot

1. Introduction

Autonomous robots refer to the agents capable of executing the specified tasks without human intervention by adjusting their behaviors based on the real environment. Mobile robots refer to those which navigate and perform tasks without external intervention. Thus, an autonomous mobile robot should be able to make decisions independently and adaptively in the real-world environments. Such robots should be able to cope with the large amount of uncertainties existing in the physical environment [1].

In recent patents, a number of autonomous mobile robots have been used in several applications. Mobile robots, today are working in almost all fields of service, and usually can be called service robots. Service Robotics is defined as those robotics systems that assist

people in their daily lives at work, in their houses, for leisure, and as part of assistance to handicapped and elderly. The International Organization for Standardization defines a "service robot" as a robot "that performs useful tasks for humans or equipment excluding industrial automation applications" [2]. Service robotics is normally divided into professional and domestic consumer services. Professional service applications include inspection of power plants and infrastructure such as bridges, logistics applications such as delivery of meals and pharmaceuticals at hospitals, as well as commercial-scale lawn and cleaning technologies. Personal service robots, on the other hand, are deployed for assistance to people in their daily lives in their homes, or as assistants to overcome mental and physical limitations. By far, the largest group of personal service robots consists of domestic vacuum cleaners; over 10 million iRobot Roombas alone have been sold worldwide, with continued growth in this market each year. In addition, a large number of robots have been deployed for entertainment applications such as artificial pets, personal assistants, etc. [3].

The worldwide number of domestic household robots will rise to 31 million between 2016 and 2019. The sales value of robots cleaning floors, mowing lawns, and cleaning swimming pools will grow to about 13 billion US dollars in this period. These forecasts are takes from the 2016 World Robotics Report, "Service Robots", published by the International Federation of Robotics (IFR) [4]

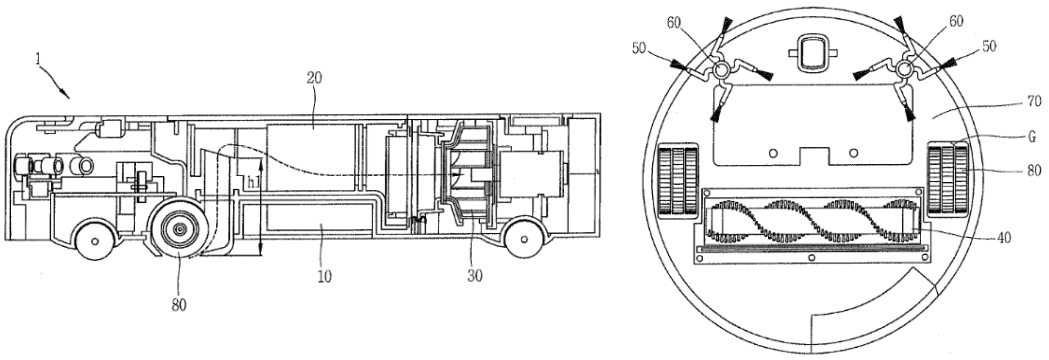
The paper is organized as follows. The next section briefly reviews the fundamental floor cleaning robots. In section 3, a recent patents of floor cleaning robots is introduced, and patents contents of floor cleaning robots are described. A method for controlling robots is proposed in section 4. This section explains systems and methods for controlling a robot cleaner of three main patentees. Applications and device inventions are based on recent patents is discussed in section 5. Finally, conclusions are presented in section 6.

2. An Overview of Fundamental Floor Cleaning Robots

Autonomous robots that perform household functions such as floor cleaning are now readily available consumer products. Commercially successful robots are not unnecessarily complex, and generally operate randomly within a confined area. Some of the available products will be described in this section.

A fundamental structure of a modern autonomous floor-cleaning robot is complicated, could be illustrated by US8733796, which is also a successful product of commercialization

today by LG Electronics Inc. The robot cleaner [5] includes a distance sensor for detecting a distance up to an obstacle, such as furniture, office supplies, walls and the like, present in a zone to be cleaned, and left and right wheels for traveling of the robot cleaner. Here, the left and right wheels are configured to be rolled by a left-wheel motor and a right-wheel motor, respectively. Accordingly, the robot cleaner converts traveling directions by itself in response to the operation of the left-wheel motor and the right-wheel motor to perform cleaning of a room. A suction element is provided within a main body of the robot cleaner, and a suction opening for sucking dust up there through is present at a lower surface thereof. Furthermore, an agitator for sweeping up dust on a floor of the cleaning zone is rotatable mounted at the inlet. A filter for filtering foreign materials in the air sucked from the floor to purify the air is provided in an air flow path within the robot cleaner. Hence, the robot cleaner sucks dust up on the floor into the main body by a suction force of the suction element and the rotation of the agitator with traveling in the cleaning zone, and collects the dust at the filter, thus to perform automatic cleaning. The collected dust is stored in a dust can within the robot cleaner. A side sectional view showing a schematic structure of a robot is cleaner according to the related art is shown in figure 1(a), a view showing a lower side of the robot cleaner is shown in figure 1(b).



(a) (b)

Figure 1 A Fundamental Structure of Autonomous Floor-Cleaning Robot in US8733796 (a) a Side Sectional View (b) a Lower Side

3. Patents

A preliminary patent search was conducted and brief summaries are given in this section.

3.1 A Recent Patents of Floor Cleaning Robots

Organized suitable search queries and obtained interested patents, a total of 12 US granted patents involving the term 'floor-cleaning' since early 2017 were found, and all of these patents are shown in Table 1.

Table 1 Search Results for Floor Cleaning Robots (Jun 5, 2014 to Feb 14, 2017)

Application No.	Patent No.	Title	Issue Date	Application Date	Assignee
US 12/836,825	US8966707	Autonomous surface cleaning robot for dry cleaning	Mar 3,2015	Jul 15, 2010	Irobot Corporation
US 14/665,626	US20150289741	Autonomous surface cleaning robot for wet cleaning	Oct 15, 2015	Mar 23, 2015	Irobot Corporation
US 14/301,454	US9445702	Autonomous surface cleaning robot for wet and dry cleaning	Sep 20, 2016	Jun 11, 2014	Irobot Corporation
US 15/085,505	US9565984	Autonomous floor cleaning with removable pad	Feb 14, 2017	Mar 30, 2016	Irobot Corporation
US 14/239,344	US20140201941	Cleaning robot	Jul 24, 2014	Aug 30, 2012	Sharp Kabushiki
US 14/132,942	US9560947	Robot cleaner	Feb 7, 2017	Dec 18, 2013	Samsung Electronics
US 14/095,303	US20140156075		Jun 5, 2014	Dec 3, 2013	Haeseock Yang
US 14/196,294	US20140257565		Sep 11, 2014	Mar 4, 2014	Lg Electronics
US 13/790,867	US20140124004	Autonomous coverage robot	May 8, 2014	Mar 8, 2013	Irobot Corporation
US 13/719,784	US8839477	Compact autonomous coverage robot	Sep 23, 2014	Dec 19, 2012	Irobot Corporation
US 13/722,566	US8978196	Coverage robot mobility	Mar 17, 2015	Dec 20, 2012	Irobot Corporation
US 13/460,261	US8881339	Robotic vacuum	Nov 11, 2014	Apr 30, 2012	Irobot Corporation

3.2 Patents Contents of Floor Cleaning Robots

An autonomous floor cleaning robot [6-8] include a transport drive and control system arranged for autonomous movement of the robot over a floor for performing cleaning operations. The robot chassis carries a first cleaning zone comprising cleaning elements arranged to suction loose particulates up from the cleaning surface and a second cleaning zone comprising cleaning elements arraigned to apply a cleaning fluid onto the surface and to thereafter collect the cleaning fluid up from the surface after it has been used to clean the surface. The robot chassis carries a supply of cleaning fluid and a waste container for storing waste materials collected up from the cleaning surface.

An autonomous floor cleaning robot [9] includes a body, a controller supported by the body, a drive supporting the body to maneuver the robot across a floor surface in response to commands from the controller, and a pad holder attached to an underside of the body to hold a removable cleaning pad during operation of the robot. The pad includes a mounting plate and a mounting surface. The mounting plate is attached to the mounting surface. The robot includes a pad sensor to sense a feature on the pad and to generate a signal based on the feature, which is defined in part by a cutout on the card backing. The mounting plate enables the pad sensor to detect the feature. The controller is response to the signal to perform operations including selecting a cleaning mode based on the signal, and controlling the robot according to a selected cleaning mode.

A cleaning robot [10] that comprises: a main case having a suction port opened in the lower surface thereof and an exhaust port opened in the upper surface thereof, that is self-propelled on a floor surface; an electric fan arranged inside the main case; a dust collection unit arranged in the center of the main case, in a planar view, that collects dust in airflow sucked in from the suction port by the driving force of the electric fan; and a battery that supplies power to each section. The electric fan is arranged on one side relative to the dust collection unit and the battery is arranged on the other side.

A robot cleaner [11] capable of moving in diverse directions and enhancing cleaning efficiency by increasing frictional force between a pad and a floor includes two or more driving units. Each of the driving units includes plural motors, a first subframe connected to at least any one of the motors and configured to rotate by receiving rotational force from the motor, a rotating plate assembly mounted to the first subframe and configured to be slanted with respect to a floor by rotation of the first subframe and to rotate clockwise or

counterclockwise by receiving rotational force from another motor, and a pad provided at the rotating plate assembly and configured to contact the floor. When the rotating plate assembly is slanted with respect to the floor, nonuniform frictional force is generated between the pad and the floor, through which the robot cleaner travels.

The robot cleaner [12] includes a main body, a voice input unit installed on the main body and comprising a microphone, a cover member to cover the voice input unit, and a buffering member provided on one of the main body and the cover member and adjacent to the voice input unit.

A robot cleaner [13] includes a cleaner body, a position sensor disposed in the cleaner body, the position sensor including a light transmission unit to emit light and a light reception unit to receive light reflected or scattered from an obstacle after being emitted from the light transmission unit, and a transparent member to transmit the light emitted from the light transmission unit and the light to be received by the light reception unit.

A mobile floor cleaning robot [14] includes a robot body supported by a drive system configured to maneuver the robot over a floor surface. The robot also includes a cleaning system supported by the robot body, an imaging sensor disposed on the robot body, and a controller in communicates with the drive system and the imaging sensor. The controller receives a sequence of images of the floor surface; each image has an array of pixels. For each image, the controller segments the image into color blobs by color quantizing pixels of the image, determines a spatial distribution of each color of the image based on corresponding pixel locations; and for each image color, identifies areas of the image having a threshold spatial distribution for that color. The controller then tracks a location of the color blobs with respect to the imaging sensor across the sequence of images.

An autonomous coverage robot [15] includes a chassis having forward and rearward portions and a drive system carried by the chassis. The forward portion of the chassis defines a substantially rectangular shape. The robot includes a cleaning assembly mounted on the forward portion of the chassis and a bin disposed adjacent the cleaning assembly and configured to receive debris agitated by the cleaning assembly. A bin cover is pivotally attached to a lower portion of the chassis and configured to rotate between a first, closed position providing closure of an opening defined by the bin and a second, open position providing access to the bin opening. The robot includes a body attached to the chassis and

a handle disposed on an upper portion of the body. A bin cover release is actuatable from substantially near the handle.

An autonomous coverage robot [16] includes a body having at least one outer wall, a drive system disposed on the body and configured to maneuver the robot over a work surface, and a cleaning assembly carried by the body. The cleaning assembly includes first and second cleaning rollers rotatable coupled to the body, a suction assembly having a channel disposed adjacent at least one of the cleaning rollers, and a container in fluid communication with the channel. The container is configured to collect debris drawn into the channel. The suction assembly is configured to draw debris removed from the work surface by at least one of the cleaning rollers into the channel, and the container has a wall common with the at least one outer wall of the body.

An autonomous coverage robot [17] includes a chassis having forward and rearward portions. A drive system is mounted to the chassis and configured to maneuver the robot over a cleaning surface. A cleaning assembly is mounted on the forward portion of the chassis and has two counter-rotating rollers mounted therein for retrieving debris from the cleaning surface, the longitudinal axis of the forward roller lying in a first horizontal plane positioned above a second horizontal plane on which the longitudinal axis of the rearward roller lies. The cleaning assembly is movably mounted to the chassis by a linkage affixed at a forward end to the chassis and at a rearward end to the cleaning assembly. When the robot transitions from a firm surface to a compressible surface, the linkage lifts the cleaning assembly from the cleaning surface.

4. A Method for Controlling Robots

Systems and methods for controlling a robot cleaner are two major topics for research and development task. The top 3 patentees who own US granted patents as shown in Table 1 are Samsung, iRobot, and LG. Accordingly, in this section, the system and method for controlling a robot cleaner of three main patentees are described.

4.1 LG Electronics Inc.

A method of controlling a robot cleaner [18] includes recognizing information on a monitoring standby position by a robot cleaner, moving to the monitoring standby position at

a monitoring start time by the robot cleaner, acquiring an image, by an image acquisition unit of the robot cleaner, at the monitoring standby position, determining whether an event has occurred, by the robot cleaner, based on the image acquired by the image acquisition unit, transmitting the image acquired by the image acquisition unit to an external remote terminal when it is determined that the event occurred. A front view and a block diagram of the robot cleaner are shown in figure 2(a) and (b) respectively.

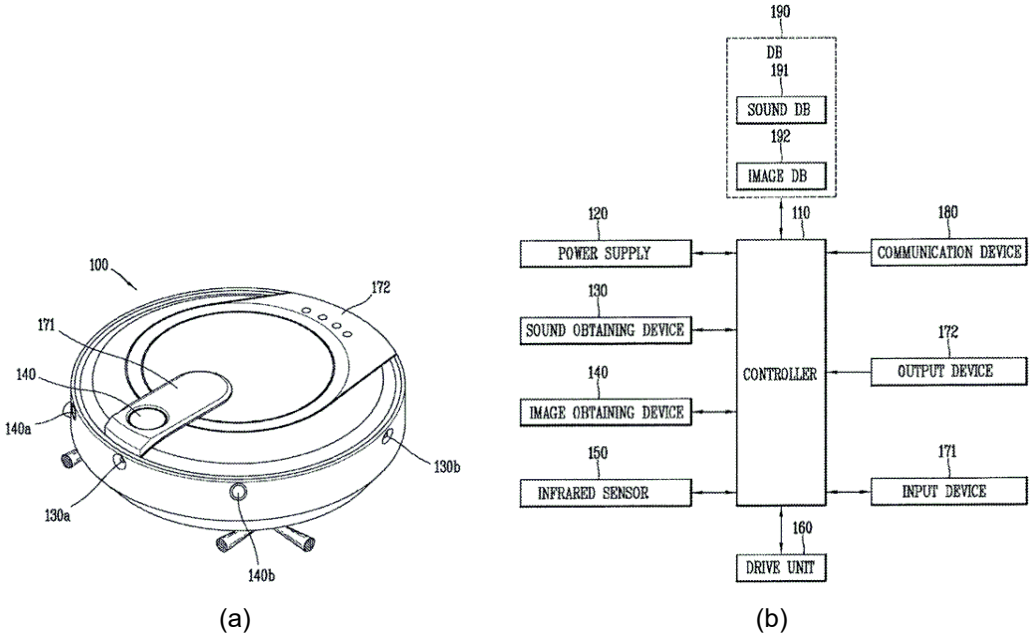


Figure 2 (a) A Front View and (b) A Block Diagram of the Robot Cleaner

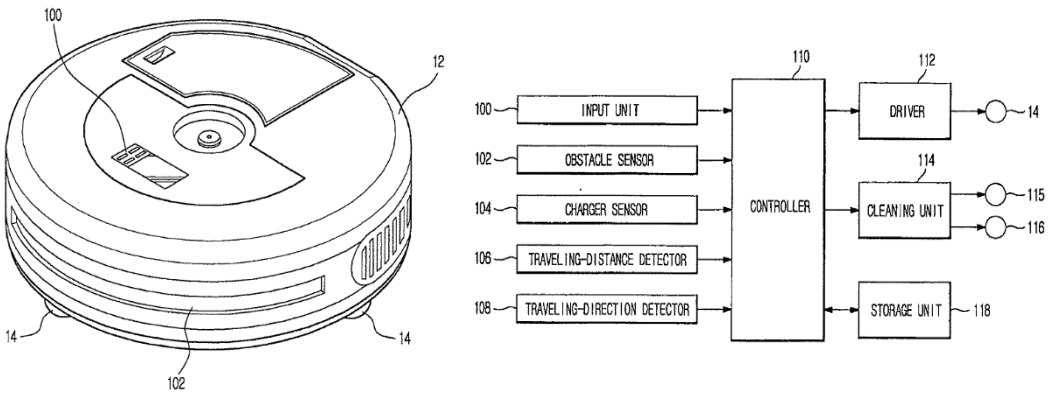
4.2 Samsung Electronics Co., Ltd.

A robot cleaner [19] to perform a cleaning process by changing a traveling pattern according to a cleaning start position and a method for controlling the same are disclosed. The robot cleaner recognizes a current position of the robot cleaner upon receiving the automatic cleaning command. If the automatic cleaning process starts from the charger, the robot cleaner performs the automatic cleaning process using a conventional cleaning method. Otherwise, if the automatic cleaning process starts from the outside of the charger, the robot cleaner changes a traveling pattern, performs the spot cleaning process and then

selectively performs the automatic cleaning process. A perspective view and a block diagram illustrating a robot cleaner are shown in figure 3(a) and (b) respectively.

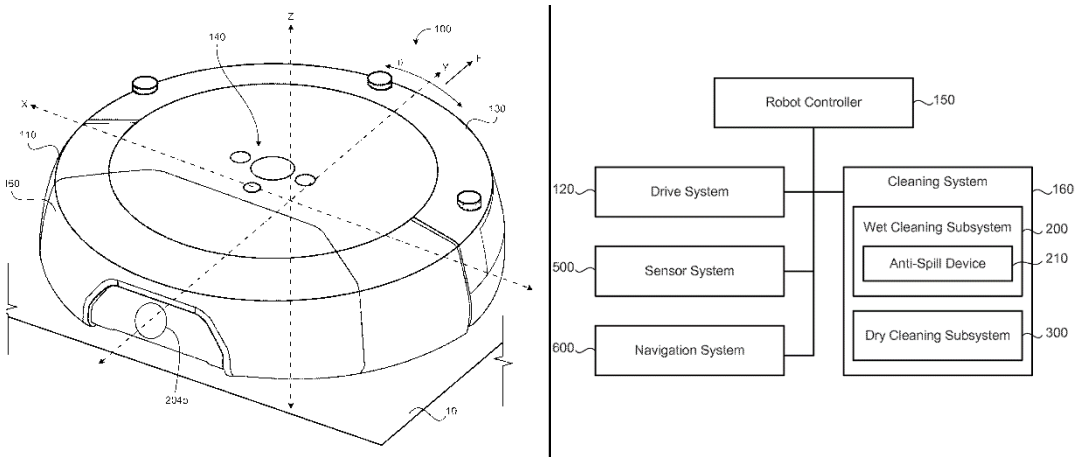
4.3 Irobot Corporation

A mobile floor cleaning robot [20] includes a robot body supported by a drive system configured to maneuver the robot over a floor surface. The robot also includes a cleaning system supported by the robot body, an imaging sensor disposed on the robot body, and a controller in communicates with the drive system and the imaging sensor. The controller receives a sequence of images of the floor surface; each image has an array of pixels. For each image, the controller segments the image into color blobs by color quantizing pixels of the image, determines a spatial distribution of each color of the image based on corresponding pixel locations; and for each image color, identifies areas of the image having a threshold spatial distribution for that color. The controller then tracks a location of the color blobs with respect to the imaging sensor across the sequence of images. A perspective view and schematic view of an exemplary wet surface cleaning robot are shown in figure 4(a) and (b) respectively.



(a) (b)

Figure 3 (a) A Perspective View and (b) A Block Diagram of the Robot Cleaner



(a) (b)

Figure 4 (a) A Perspective View and (b) Schematic View of an Exemplary Wet Surface Cleaning Robot

5. Applications and Device Inventions are based on Recent Patents

The numbers of floor cleaning robot's patents have been commercialized. Some of the available products will be described in this section.

Irobot has been launched Roomba Vacuum Cleaning Robot [21], which is also a successful product of commercialization today. Roomba 800 Series robots use the revolutionary AeroForce™ Performance Cleaning System to clean floors like no vacuum has ever cleaned before. Proven to remove up to 50% more dirt, dust, hair and debris than previous Roomba models, Roomba 800 Series delivers maximum cleaning performance with less maintenance hassle.

LG's newest robot vacuum, the Hom-Bot *Square* [22], which has an attractive with a sleek, rounded-square design that LG claims helps the Hom-Bot clean corners more effectively. The true implication is that the Hom-Bot cleans corners more effectively than the Roomba, and indeed, much of the Hom-Bot's design seems specifically intended to one-up the Roomba wherever possible. The Roomba has one sweeping brush - the Hom-Bot has two. The Roomba has one primary cleaning mode - the Hom-Bot has two, plus five additional modes.

The Samsung navibot SR8855 [23] is a low-lying circular device that scurries around a house, automatically navigating its way round, cleaning the floor as it goes. It incorporates

a conventional cylindrical brush as well as brushes for prizing dirt out of corners and uses a combination of sensors and cameras to work out where it's going. Unlike the iRobot Roomba, which is arguably the most famous of these devices, the navibot actually maps out rooms and works out the quickest way to work its way round.

Early in the development of the technology, a robot vacuum could only act solely as a vacuum for floors. In the present day, as greater demand for the concept has allowed technology in this area to develop, a number of additional cleaning features (such as mopping and sterilization) are being introduced to newer models. Most of floor cleaning robots have a similar design structure; they are as compact and flat as possible without hindering performance. This is so that they can move freely under furniture and clean as much area as possible. A lot have a base unit that they return to on completion of their cleaning tasks, which recharges their power for their next scheduled use. The most sophisticated models of floor cleaning robots have an inbuilt mechanism that allows them to pick up exactly where they last left off.

6. Conclusions

A search queries in patent database can obtain an overview for a technical topic quickly. The top 3 patentees who own US granted patents are Samsung, iRobot, and LG. Among them, Samsung leads in patent numbers of cleaning robots, both applications and granted. Samsung also leads in camera photographing and remote control though. In the cleaning tools, iRobot is strong in brush, wet and dry cleaning, debris detecting and collecting, all of these are important for an automated robot. IRobot also takes lead in cleaning mode and obstacle avoidance. It is interesting that coverage and escape behaviors are powerful in cleaning, especially under tables, chairs, cabinets, or beds, which are inconvenient to clean by human being. LG robot cleaner having a monitoring function and minimizing power consumption and/or securing communication efficiency, thereby minimizing power consumption of the robot cleaner with limited power.

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