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Autonomous Cleaning Robot: Roboking System Integration and Overview

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***Abstract* - This paper will present the system integration and overview of the autonomous cleaning robot Roboking. Roboking is self-propelled autonomously navigating vacuum cleaning robot. It uses several sensors in order to protect indoor environments and itself while cleaning. In this paper, we will describe the principle of operation along with system structure, sensors, functions and integrated subsystems.**

Index Terms* - *Robot; LG; Vacuum; Autonomous; Sensor

I. Introduction

Industrial robotics research has been around since long time ago. However robots as a home appliance emerged recently and as the people's need and market grows, home appliance robotics research is becoming active more than ever. If a household can afford humanoid robot as a maid, it would be ideal but unfortunately humanoid robotics research is still ongoing and it is too expensive for average household.

We aimed at more specific function of the robot. Since it does not require any complex moving parts and people want to get way from tedious everyday cleaning job, our team decided to engage in the development of an autonomous vacuum-cleaning robot. There are several big bulky cleaning robots in the market for places such as supermarkets, offices and so forth but they are not autonomously operated. We set a goal to come out with a system, which navigates while avoiding obstacle, wall and cliff detection & following feature along with finding its way back to the charging station when cleaning is done or battery power level is low. At the same time, the size should be compact enough for the use in average size house and fail-safe feature for consumer protection.

Roboking gathers environment information for navigation from several ultrasonic sensors and infrared sensors. Also it finds its way back to the charging station from rotating infrared sensors on the top portion. DSP gathers information from various sensors and makes decision. Details will be presented later in this paper.

II. System Structure

Roboking uses Texas Instruments 320LF2406A digital signal processor (DSP)for decision-making. The DSP runs at 40 MHz with 40 MIPS (Million Instructions Per Second) performance, which gathers signals from 24 sensors onboard and other information from internal subsystems. There are 14 ultrasonic sensors installed; 5 sensors on the upper portion of the robot for detecting tall obstacles and 9 sensors on the lower portion are used for finding flat obstacles and general navigation. 4 infrared seeking sensors are mounted on the top of the robot. The sensor-mounted plate has a turret mechanism, which can be rotated to scan the location of infrared signal emitting charging station. There are also 4 cliff detecting sensors, which are infrared distance measurement sensors, on the bottom of the robot. Cliff detecting sensors keep Roboking from falling down or determine whether it is lifted up. Two tactile sensors are installed in the bumper for detecting small or slender objects, which ultrasonic sensors cannot find. They are installed on two corners on front so that they can determine and react collision from left, right and middle accordingly. The DSP controls all motors onboard and battery management system.

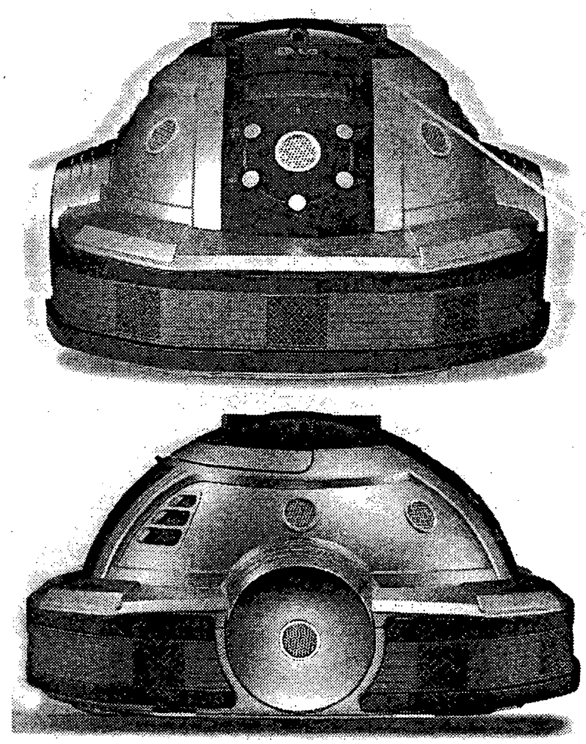

Fig 1. Roboking

Fig 2. Previous prototypes

III. Sensory Systems

A. *Ultrasonic Sensors*

14 Ultrasonic sensors are installed on Roboking. Each sensor is capable of both emitting and receiving 40 kHz ultrasonic waves. Ultrasonic sensors are configured to detect obstacles every 18ms, as far as 1.2m away and as close as 4 cm. Since they are capable of receiving signal as well as emitting, neighboring sensors receive reflected signal and determines the distance from the robot to the obstacle. This process is alternated from sensor to sensor and it takes about 0.1s to complete one full cycle, including processing time. Figure 4. shows the execution order. Numbered box is the ultrasonic signal emitting sensor and neighboring boxes are receivers. DSP renders a map of immediate surroundings of the robot and decides what to do next according to the programmed algorithm.

B. *Infrared Sensors*

1) Infrared Seekers

4 infrared seeking sensors are mounted on the top plate on the robot. The top plate has a turret design and is rotated by the servomotor underneath it. When robot is low on power or finished cleaning, it will scan for the charging station, which constantly emits modulated infrared signal when robot is not connected to the station. The signal from the charging station can reach up to 1m; therefore if the robot is out of the range from the infrared origin point, it will randomly wander and scan for the signal from the charging station until the beam is found. Once the signal is found, it will determine the distance and angle of the charging station from rotating infrared seekers and approach the approximated location. Second scan will be performed prior to the docking process for precise location determination. Since the beam angle from the charging station is about +/- 20 degrees, Roboking can precisely find docking point as it approaches the charging station.

TABLE I
Roboking Hardware Specification

Length	414 mm
Width	343 mm
Height	216 mm
Weight	6 kg
Power supply	12V / 3Ah (Ni-MH)
Maximum velocity	0.4 m/sec
Ultrasonic sensors	14 (Navigation purpose)
Ultrasonic frequency	40 kHz
Infrared distance sensor	4 (Cliff detection)
Infrared seeking sensor	4 (Charging station seeker)
Tactile sensor	2 (Bumper)
Encoder	2 (Propelling motor)
DC Motors	5
Servomotor	1

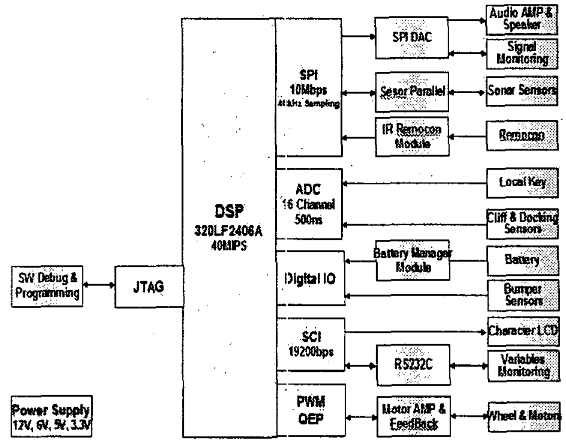

Fig 3. System circuit block diagram

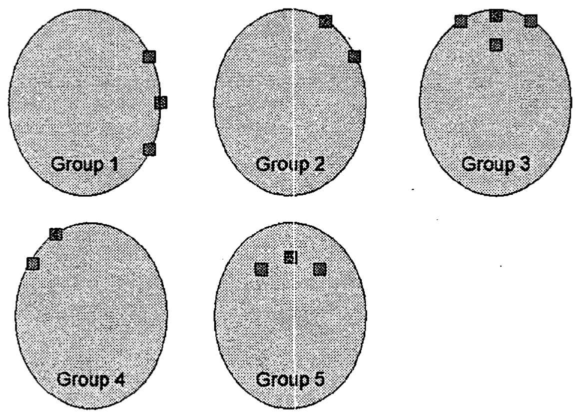

Fig 4. Ultrasonic sensor execution order

2) *Cliff Detection Sensors*

4 infrared distance measurement sensors are installed on the bottom plate of the robot. Two of them look about 5cm ahead of its path and other two look 5cm away of starboard side of the robot. Frontal sensors are located on front left and right corners - they work as like antennae – they constantly look for the ground and finds cliff once the measuring distance suddenly increase by degree. Two sensors on the starboard side are located in front and right after wheel. They are used when Roboking navigates parallel along cliff line. Combining all the cliff sensors not only prevents Roboking from falling

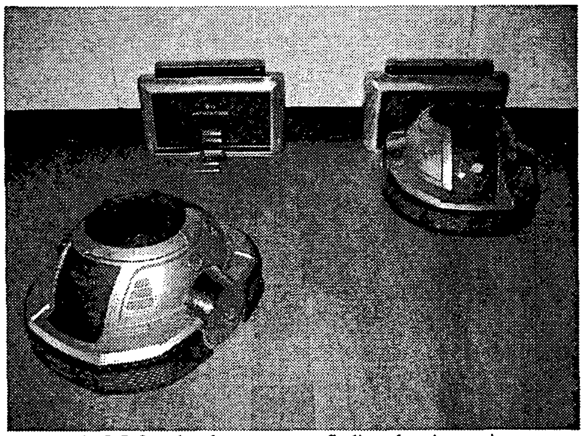

Fig 5. Infrared seekers on turret, finding charging station

down but also enables to follow any cliff line. Roboking can also detect itself from being lifted when all the cliff sensors simultaneously sees distant surface.

C. *Tactile Sensors*

Two tactile sensors are located on right/left corner of the bumper. When bumper hits small and/or slender object, which is not detectable by ultrasonic sensor, robot determine which sensor is pressed and it executes obstacle avoidance algorithm. Signals from two tactile sensors are combined to figure out whether the collision point is right, left or center.

IV. HARDWARE FEATURE

The main suction power comes from 12V, 70W DC motor. It has an attached impeller with 100mm diameter. Since the suction power is not comparable to general household vacuum cleaner due to different power source, oppositely rotating twin agitator helps sucking up dust particles into the suction nozzle. Each rotating brushes are powered by dedicated DC motor. Navigation motors are 12V, 15W with gear-heads, which have 72:1 reduction gear ratio. The DSP controls navigation motors based on the information from attached encoder, which has 180 Count per Revolution(CPR) resolution.

V. SOFTWARE SYSTEM

A. *Wall-following*

In normal cleaning mode, Roboking will clean the perimeter of the room by following walls in counter clockwise direction. While in wall-following mode, the robot keeps track of its position by counting the pulse from encoders. Once it reaches the starting point after finishing border navigation, the robot sets cleaning time according to the length of the room perimeter and starts cleaning in random mode. Therefore it is necessary to operate Roboking in enclosed area, otherwise it will keep following walls until battery runs out. If it is necessary to operate Roboking in open area, random cleaning mode should be used. Roboking will go straight until it

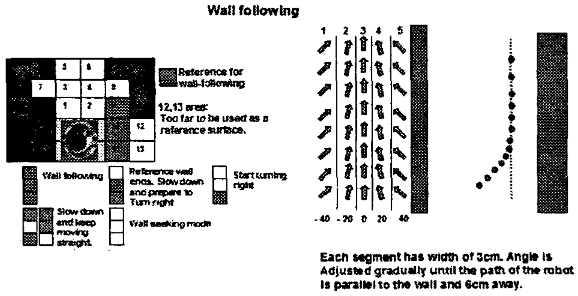

Fig 6. Wall-following method

detects any obstacle and it will rotate in random angle for the next straight path until it reaches another obstacle.

Figure 6. shows how the robot determines to follow walls. Normally robot keeps 6 cm distance from wall. If it is closer or farther than 6 cm from wall, Roboking will adjust its path angle accordingly as shown in Figure 6.

B. *Cliff-following and Avoiding*

Cliff is considered same as wall, however cliff is sensed through infrared distance measurement sensor. When cliff is detected on frontal part of the robot, robot rotates until floor surface appears again. Then robot proceeds straight until the frontal sensor detects cliff again. Roboking will repeat rotation and straight until the path is parallel to the cliff and two side sensors detect floor, as shown in Figure 7. When the edge line is rounded, Roboking will perform same procedure, however, smooth cliff edge following will not be exhibited.

Figure 8. is when Roboking finds another cliff while following the edge. From two side range finders, Roboking knows there no wall but cliff on right side. If there is wall, the robot will enter wall-following mode again but if not, Roboking will rotate and repeat previously mentioned procedure again as shown in Figure 7.

C. *General Navigation*

Once Roboking comes back to its starting point - usually the charging station - from wall-following and cliff-following, it will continue the size of room and set cleaning time

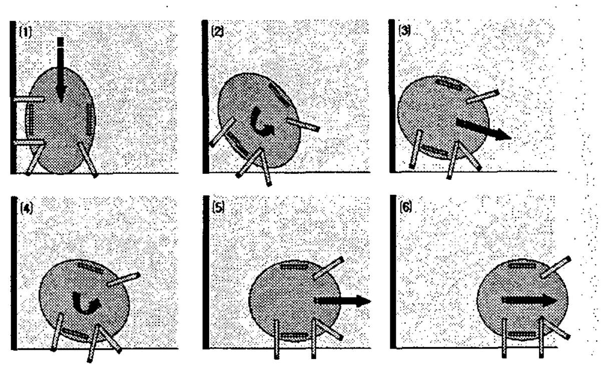

Fig 7. Cliff-following method

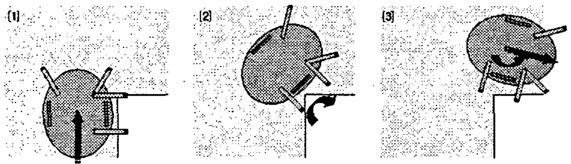

Fig 8. Continuing on neighboring cliff

according to the calculation. Then random navigation will begin for given time while cleaning the room. If user wishes to use Roboking in open space or start random cleaning right away, cleaning time can be entered manually through control panel. If cleaning time is not specified in random cleaning mode, it will operate for 10 minutes. After cleaning is done, it will initiate charging station searching mode.

D. Docking Method

When infrared signal is found from the charging station, Roboking will begin docking procedures. It will measure its orientation relative to the wall with ultrasonic sensors. Therefore, charging station must be placed against flat wall. Roboking will approach the charging station in parallel and rotate 90 degrees and reverse for charging point connection. If electrical terminals are not connected properly, it will attempt angle adjustment for 3 times. If reattempt is not satisfactory, Roboking will repeat the whole procedure all over again until electrical points are connected. Figure 9. illustrates the docking procedure.

E. User Interface

Several features and modes can be selected and stored into the system according to user's need. User interface menu has tree structure as shown in Figure 10. Selection is made through 5-button control panel in front of the robot and the result and current status is displayed on 32-character monochrome LCD display window. There is also a IR remote controller for Roboking. Manual operation, direction control, function selection and with IR turret on top, calling to the remote controller location is possible with provided controller. Currently, a plan to upgrade the display to color LCD is being evaluated.

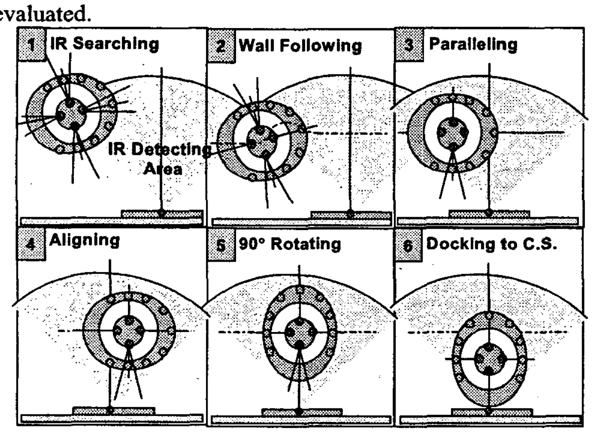

Fig 9. Docking procedures

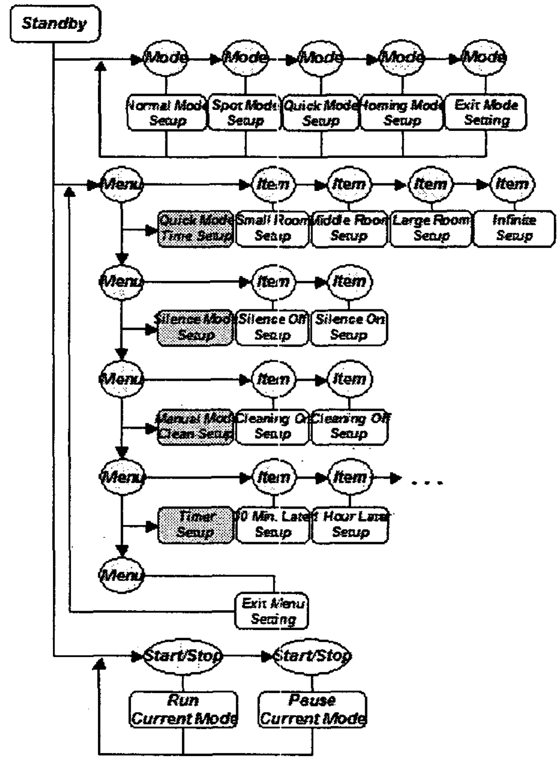

Fig 10. User interface menu tree-structure

VI. Conclusion

Our team integrated several features into Roboking but we also know there are many parts to be improved. For example, the user interface menu structure is quite complicated, it needs some simplification since most of the users will not be engineers. Also sensory systems should be more reliable and robust.

We are constantly improving the current model. At the same time, our team is on the development of the second-generation product. The second generation Roboking will be a part of LG HomNet® system, which is a home appliance network that enables to control all home appliances from anywhere at anytime. The second generation Roboking will not only clean house but also act as a home monitoring & security agent. Due to the nature of commercial product research and development, detailed specifications cannot be disclosed at this moment but it will come out in the market in near future with many advanced features.

We all know Robots will be around with big impact in our life just as the internet did a few years ago. It is hard to predict when the robots in the consumer market is going to boom up but the decision was made to start this project in order to gain consumer robot R&D experience for the near future. This project will continue even though there is no big demand from customers or profit from Roboking. Updated news will be posted on our website at http://www.lge.com.

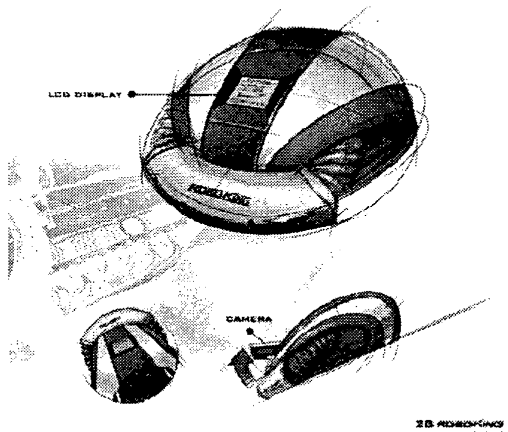

Fig 11. Conceptual design of the next generation Roboking

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