Autonomous Omni-Directional Cleaning Robot System Design

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Abstract: In this paper, an autonomous omni directional cleaning robot which recognizes an obstacle and a battery charger is introduced. It utilizes a robot vision, ultra sonic sensors, and infrared sensors information along with appropriate algorithm. Three omni-directional wheels make the robot move any direction, enabling a faster maneuvering than a simple track typed robot. The robot system transfers command and image data through Blue-tooth wireless modules to be operated in a remote place. The robot vision associated with sensor data makes the robot proceed in an autonomous behavior. An autonomous battery charger searching is implemented by using a map-building which results in overcoming the error due to the slip on the wheels, and camera and sensor information.

Keywords: Cleaning robot, obstacle avoidance, sensor fusion, robot vision, Blue-tooth

1. INTRODUCTION

As a computer expands to all technological societies, a robot system has a strong linkage to home appliances in incorporating with IT, BT, and NT based technologies. Moreover, an intelligence on the robot system inevitably is embedded to carry out more specified and complex works. An intelligent robot is categorized into an industrial and home robot [1] and the home robot is again classified into a human service robot and home service robot. The latter works at home for a human in the area of cleaning, monitoring, and pet care, etc. The cleaning robot is most advanced and commercialized and many new techniques have been updated.

In this paper, the cleaning robot focuses on the autonomous function enhancing a cleaning performance. This robot avoids an obstacle effectively with camera vision information and appropriate algorithm. The battery charger is identified and the robot approaches it, being charged automatically. Desks, chairs are normally identified as obstacles to interfere the robot's movement. The robot compasses a vision sensor and 6 ultra sensors, and 3 infrared sensors around the robot body, and these sensors are utilized for a sensor fusion [2] which integrates the vision information and sensors data. Two limit switches play a role in identifying and compensating the battery charger by the help of vision camera. The robot detects the obstacle by a vision first, and two ultra sensors are integrated to determine the distance between the obstacle and robot. In the mechanism of the robot, an omni-directional wheel [3-5] is adopted to maximize robot's movement and fast turning.

In this article, the robot mechanism and its characteristics are introduced and the algorithm for cleaning and a robot vision method for avoiding an obstacle are also addressed. The travel motion control on the omni-directional wheel and vision process algorithm, and command transfer via a blue-tooth module are introduced.

2. ROBOT MECHANISM

A mobile robot is classified into a wheel type robot [6-7] and a biped robot [8-10]. The wheel robot has advantages in regarding to direction turning, and obstacle avoidance over the biped robot. However, it has demerit in climbing a stair or passing a hazard. The cleaning robot here takes omni-directional wheels to compensate the demerit of the wheel type robot (Fig. 1). The omni wheels make the robot move randomly and cover the more space effectively due to its small turning radius. The three wheels locate with 120 degrees each other and the camera scanning devises are not specially necessary for a scanning function.

Fig.1 The Structure of the omni-directional robot

A cool muscle motor is employed where the motor driver is inside of the motor and 32 bits RISC CPU chip is on the driver board. The cool muscle provides several communication interfaces such as a computer, pulse, and analogue. Also the motor possesses a location sensor with 50,000 pulses/revolution and keeps a smooth operation in low speed region. A simple programming job is also provided [11].

3. CONTRL SYSTEM

3.1 Outline of control system

The cleaning robot consists of a high level and low level structure in the control structure. The high level control consists of a personal computer and the low level has a microcontroller (PIC16F874, [12-13]). The main role of the high level control is to analyze the images acquired from the CCD camera via RF image module and later delivers the analyzed information to the low level to compare the information collected from the low level control. Finally the control commands are transferred to the omni-wheels via a blue-tooth module. On the contrary, the lower level control takes information coming from the six ultra sound sensors, three infrared sensors, and two limit sensors. With integrated information and analysis between the high level control and low level control, the robot can moves without colliding with obstacles and can travel straight or turn as fast as possible. [Fig.2] illustrates a control flow for the cleaning robot and the system block diagram is shown in Fig. 3.

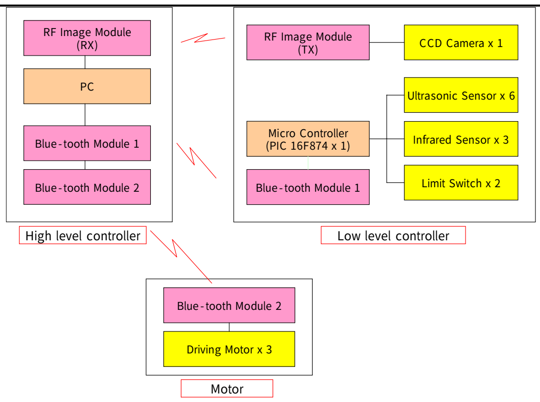


Fig. 2 Control flow of cleaning robot system

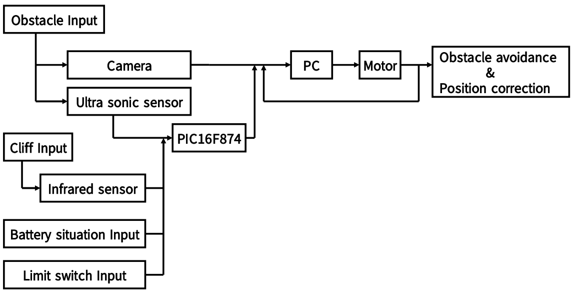


Fig. 3 Block diagram of cleaning robot system

The interface between the high and low control is done by a bilateral blue-tooth module (Promi-SD202, INITIUM BT [14]) and a RS-232C protocol (Fig. 4). The communication packet is shown in Table 1. P represents a preamble and its value is assigned 0x55 in consideration of mark/space ratio. F is the initial byte checking the correct start bit from the continuous data coming from a serial port, and its value is assigned 0xFF in this protocol. S represents an address value for a starting byte, D1 is the first data, D2 is the second data, and C is a check sum checking a complete data transfer. Finally, E is the end byte and a predetermined address is assigned in it. This multi protected data structure eventually enables to guarantee the correct data delivery.

Table 1 Communication packet

P	P	P	F	F	S	D1	D1	C	E

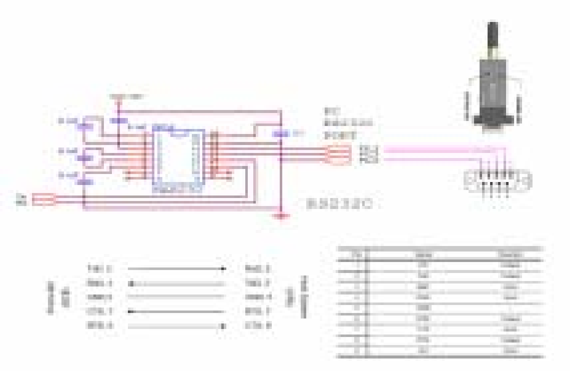


Fig. 4 Blue-tooth communication circuit

3.2 Sensors installation and fusion

The ultra sound sensors aim primarily at detecting and avoiding obstacles and those appropriate locations are crucial. Usually, desks and chairs which are main obstacles at home are placed at certain location but some times those are randomly placed. Thus, the robot needs to be designed adaptively to overcome this kind of uncertain placement.

The location of ultra sound sensors and infrared sensors are shown in Fig.5.

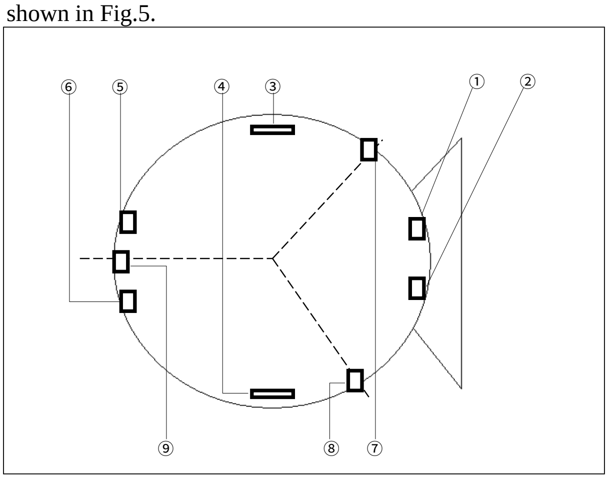


Fig. 5 Sensors location for a cleaning robot

① through ⑥ are ultra sound sensors and the infrared sensors are denoted at ⑦ through ⑨. Sensors ① and ② are located in front of the robot to detect the obstacle ahead. Due to the limited capability only by the camera to determine the distance from the obstacle and uncertain data under the different environment such as light intensity and noise, the complementary sensors with ultra sound or infrared sensor are installed additionally. When there is an obstacle ahead, the programmed algorithm issues a command after comparing the vision information and ultra sound sensor data whether the robot can proceed or avoid. Particularly, ⑤ and ⑥ are sensors used to detect a battery charger with a simple on-off output. When the robot finds a location of the battery charger by a vision image the robot approaches it, and the switches are used to compensate the robot posture. When two ultra sensors receive an ON signal, the robot recognizes that the charger is located 15 cm back of the robot body.

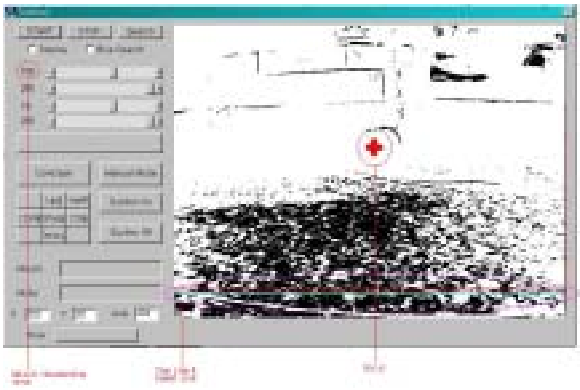
3.3 Vision sensor installation and image identification

The high level control is composed of Pentium-IV class to execute a complicated image data processing. The program on the high level control is based on Visual C++ 6.0 and the main roles of it are primarily serial communication, CCD camera image monitoring, obstacle detection and avoidance algorithm, and its image analysis. The main subject of image identification is on edge lines detection appeared to desks or chairs. Excluding a color data, an edge detection can be mainly employed in this robot system. The edge detection can be carried out by using the sharp data change after taking first or second differentiation of the intensity along with a specially designed 3x3 mask [15-16].

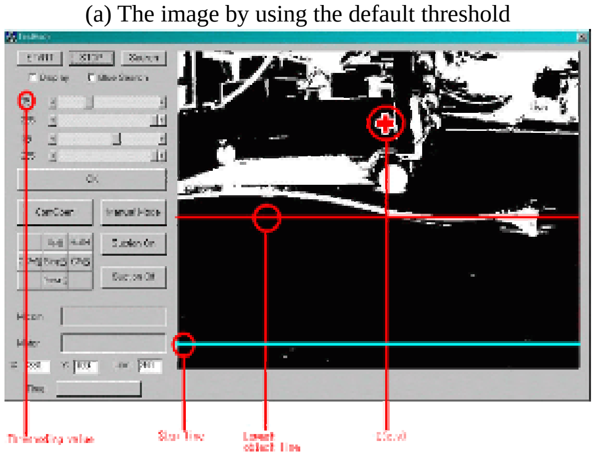
An image analysis starts from obtaining the center of the object and later turns 90 degrees, and the turning angle is for maximizing the obstacle avoidance. An image area is determined based on 640x480 (pixel) and the center of the image $G(x, y)$ is calculated as

$$G(x,y) = \frac{\sum_{a=0}^{n-1} x_a + \sum_{a=0}^{n-1} y_a}{n}$$

Here, x_a is the x-coordinate value and y_a is the y-coordinate value, respectively.



(a) The image by using the default threshold



(b) The image by using the modified threshold value

Fig. 5 Binary image processing by different threshold values

Next, an algorithm for obstacle avoidance is addressed. The green line in Fig. 5 represents a stop line for a robot to be stopped, and the red line denotes a bottom line of the detected obstacle. When the robot proceeds, the obstacle ahead of the robot is detected by a camera first and is identified clearly by the two ultra sound sensors. The ultra sensor, as explained before, is used to measure the distance of the obstacle and to compensate the uncertain image feature obtained by camera. Two sets of ultra sound sensors are set to detect an object 20 cm ahead of the robot. When the camera detects a red line, the ultra sensors start activating to determine whether the object is located in the range of 20 cm from the robot.

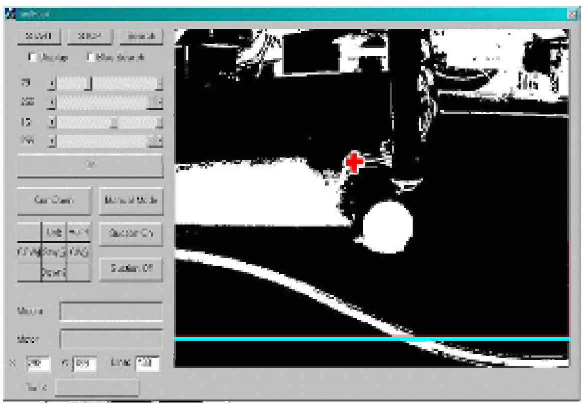


Fig. 6 The image of when lowest line and stop line are identical

If the sensors detect the object and the camera image takes a red line simultaneously, the object is identified as an obstacle and image data and sensor data are stored in a memory in the computer, then the obstacle avoidance algorithm begins an operation. As the robot moves forward the red line and the green line (stop line) aligns together, the robot turns 90 degrees angle in the direction of x-coordinate of $G(x, y)$, completing an avoidance. The image acquired after turning is shown in [Fig. 6]. Fig.7 shows the flow chart of the cleaning robot movement which includes a traveling and obstacle avoidance.

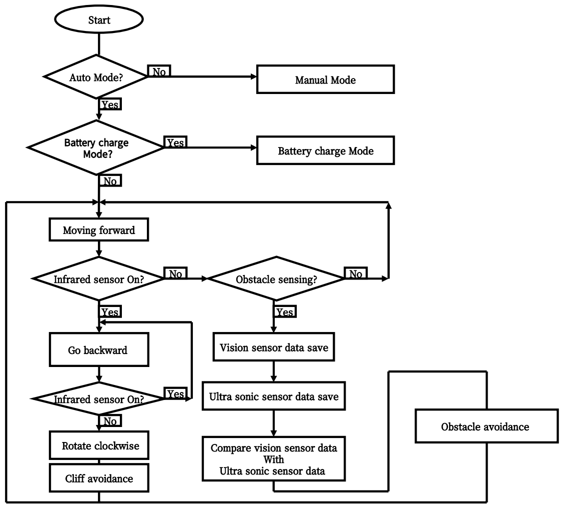


Fig. 7 The proceeding flow of the omni directional cleaning robot system

3.4 Robot motion control

In this section, a way how three omni-wheels velocities can be determined as the robot velocity in the direction of x-y is set beforehand is addressed. In case the obstacle should be avoided or the robot moves forward, the robot velocity (V) and its orientation (θ) should be determined first.

Let r be the wheel radius, b be the distance to the wheel center from the body center, v_0, v_1, v_2 be the linear velocities of wheels, and F_0, F_1, F_2 be the unit vector. w is the angular velocity and n represents an index of the each wheel. As seen from Fig. 8 the unit vector is written as

F0 = [-1, 0], F1=$[\cos 60^0 \ \text{-}\sin 30^0]$, F2= $[\cos 60^0 \ \cos 30^0]$

From the geometric condition, the following equations hold

$$v_x = F_{0x} v_0 + F_{1x} v_1 + F_{2x} v_2$$

$$v_y = F_{0y} v_0 + F_{1y} v_1 + F_{2y} v_2 \qquad (1)$$

Using the unit vector $[F_0, F_1, F_2]$, the velocity of x and y directions are determined as

$$v_x = -v_0 + \cos 60\, v_1 + \cos 60\, v_2 = V \cos\theta$$

$$v_y = -(\cos 30) v_1 + \cos 30\, v_2 = V \sin\theta \qquad (2)$$

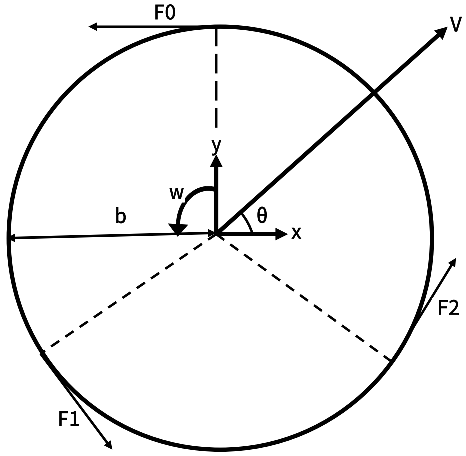


Fig. 8 Geometry of the omni-directional wheel

Therefore, the linear velocities of three wheels can be seen that

$$\begin{aligned} v_0 &= -V\cos\theta \\ v_1 &= V\cos\theta\cos 60 - V\sin\theta\cos 30 \\ v_2 &= V\cos\theta\cos 60 + V\sin\theta\cos 30 \end{aligned} \quad (3)$$

Here, again, V is the robot velocity and θ is the orientation of the robot measured from x direction.

3.5 Autonomous battery charging by camera and ultra sound sensors

An autonomous battery charge is a big issue in terms of reducing human labor and increasing human spare time at home. Here, an autonomous battery charge algorithm and mechanism are addressed. First, a map-building is constructed for monitoring the current robot location by displaying it in a computer screen and checks the error between actual location of the robot and calculated location (Fig. 9). Actually, the robot adopts omni-direction wheels which give rise to a slippage on each wheel. Only by the encoders data, it is not clear to calculate the exact location of the robot. An operator can monitor how much error occurs by taking look at the window and real robot.

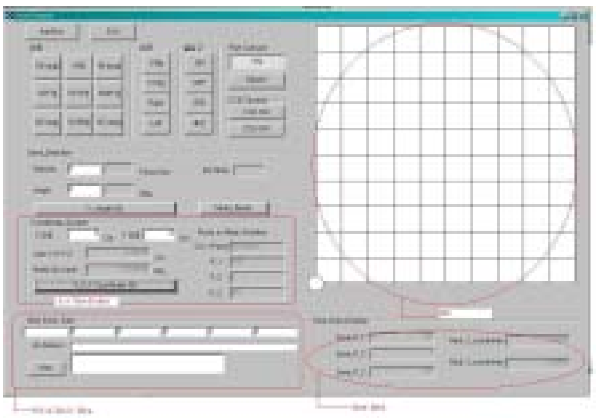


Fig. 9 Program environment for a map-building

When the battery charger signal is turned on, the robot starts moving to a battery charger which can be identified by using a camera and two ultra sensors. The robot tries to approach charger closely by scanning the camera to search for the charger which is stored beforehand with a digitized image of circle type of 10 cm diameter. When the scanned image approximately matches with the preset data for a charger, the robot starts moving to the charger. When it reaches the charger, the robot turns 180 degrees and move backward until two ultra sensors turn on which is preset with 20 cm distance apart initially. Additionally, two limit switches placed at the back side of the robot keep functioning until the posture of the robot is almost fit to the charger. On the left window of Fig. 10 shows the matched image of the battery charger, which comes from the unmatched scanned image shown at the right side of the window.

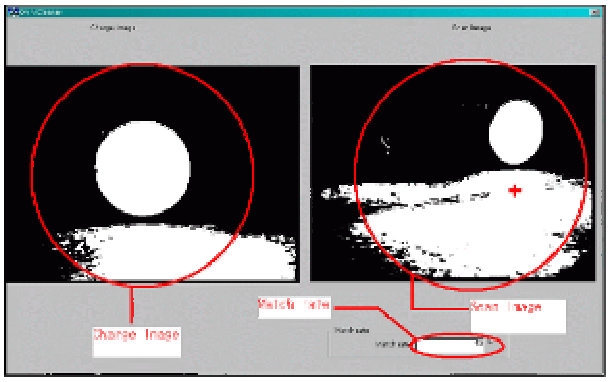
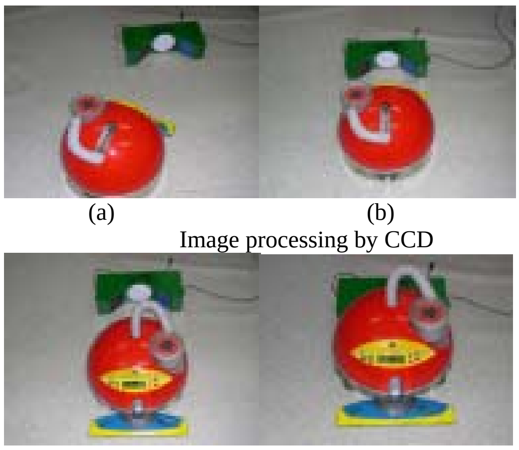


Fig.10 The Image of Battery charge mode

4. EXPERIMENTAL RESULTS

After installing all sensors and communication modules, the performance of obstacle avoidance and battery charger search is tested. It results in 200mm/sec movement in avoiding an obstacle and 70% cleaning capability is verified. The other 30 % is untouchable space to be cleaned such as a narrow corner. All sensors and camera actually cooperate based on the programmed algorithm, and a sensor fusion is carried out without any hassles or difficulties. Also, the data or image transfer between microcontroller and computer which is done by a blue-tooth module results in successful outcomes. Fig. 11 shows the process of finding a battery charger and approaching it autonomously.



(a) (b)

Image processing by CCD

(c) (d)

Position control by ultra sonic sensor

Fig.11 Demonstrations of auto battery-charging processes

5. CONCLUSIONS

An omni-directional wheel type cleaning robot which tackles an obstacle and guarantees a fast moving and turning associated with ultra sensors, CCD camera, infrared sensors, and wireless data transfer by blue-tooth module is addressed. The sensors data and camera image are fused to identify the obstacle and to find the battery charger. The image process enabling to obtain clear and correct information of the object is done and its results show a satisfactory outcome. The remained amount of battery capacity is always checked on line, and when the robot runs short of battery, the robot finds it and contacts it by scanning the environment and checking the distance of it. To compensate the error between the actual robot location and estimated location of the robot due to inevitable slippage on the wheels a map-building is constructed for an operator to monitor the error effectively. With more strict and punctual algorithm, the robot can be robust to environment variation, be faster in movement, and be less error in cleaning.

5.1 References

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