A House Cleaning Robot System
–Path indication and Position estimation using ceiling camera–

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Abstract: Finding the desired path for a mobile robot in order to perform cleaning efficiently is a difficult task. Moreover, in complex indoor environments, mobile robot position estimation and its correction remains to be one big problem. This paper describes a cleaning robot system, which is composed of path indication and auto position estimation. This system allows the user to teach the robot a determined cleaning path and provides long time cleaning stability.

Keywords: Cleaning robot, Path indication, Position estimation

1. INTRODUCTION

Recently, research on housework automation kept the attention of many researchers. One of the most desired works is house cleaning task. In fact, many cleaning robots have been commercialized so far. However, past cleaning robots have not spread to ordinary families because still there are a lot of imperfect elements. Important functions for a cleaning robot are: (1)Sucking garbage, (2)Autonomous moving, (3)Deciding an area that should be cleaned. The many marketed robots achieved (1) and (2). On the other hand, it is a difficult problem to decide the running route automatically. We developed a system that will efficiently clean only the selected places from the user. Moreover, in order to move long distances accurately, a LED is mounted on the robot. An accurate robot's position can be estimated by tracking the LED from a camera fixed to the ceiling of the room to be cleaned.

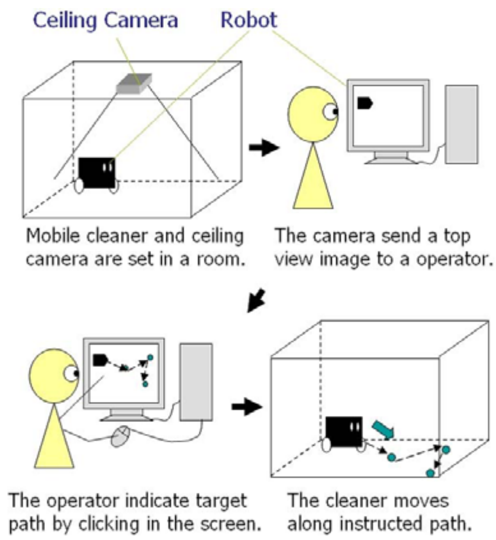


Fig. 1 The concept of house cleaning robot system.

2. SYSTEM OVERVIEW

The concept of this system is shown in Fig.1. First of all, a camera is set in the ceiling of the room to be cleaned in a position in which it can have a complete view of the floor. Then, camera takes images of the floor and transmits them to the user's PC display. Next, the user selects the paths to be cleaned by clicking one by one on the screen. Then, clicked coordinates are forwarded to the robot, and the robot autonomous runs as directed.

All selected areas to be cleaned can be efficiently sucked. Moreover, it is possible to avoid robot approaching certain places. This system proves to be safe because the user can observe the environment with his own eyes, and use this system at ease. Of course, the automatic cleaning robot can be operated even from outside of the house via the internet. As web cameras became cheap, the installation cost is low.

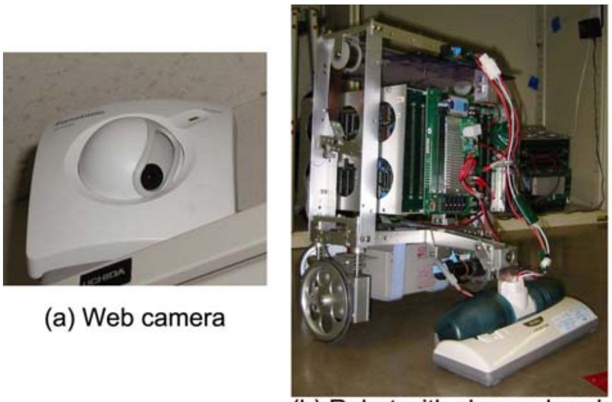
When the robot moves in the indoor environment, Odometry information gradually becomes untrustworthy by hitting obstacles, or slipping on carpets. Though a large amount of methods for robot self-positioning using various sensors are proposed, in actual home environments there are plenty of obstacles around the robot making difficult to find and measure landmarks for correcting position. This system calculates a relative position of the robot by using the camera fixed to the ceiling. As a result, the position and posture can be measured and corrected.

3. SYSTEM STRUCTURE

Fig.2 shows the composition of the system. This system consists of a mobile robot with a cleaning head, a ceiling camera, and user interface for path indication.

3.1 Cleaning Robot

A YAMABICO series mobile robot is used in this research. YAMABICO is a mobile robot equipped with two independent steering wheels. Its body size is about 40cm



(a) Web camera

(b) Robot with cleaner head

Fig. 2 Camera and mobile cleaner.

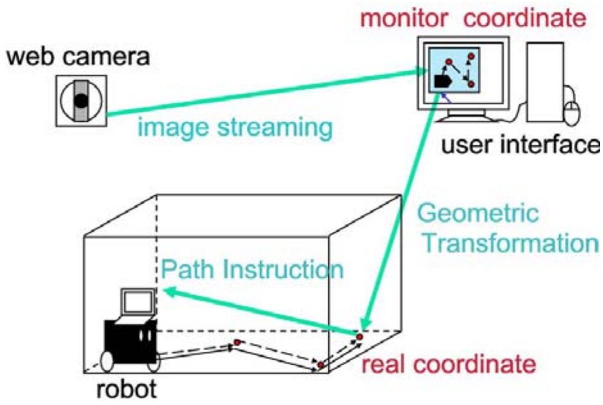


Fig. 3 Data flow.

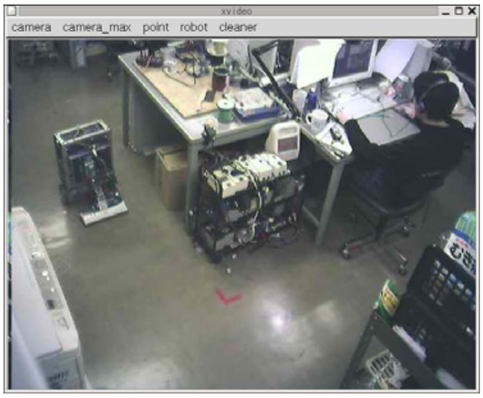


Fig. 4 Image taken from ceiling camera using GTK+

square. By default, it is able to move autonomously along a specified line[1]. The front wheel caster of this robot is replaced with a hand cleaner. Then, when the robot moves, dust and garbage can be absorbed along the running route. The switch of the cleaner connects with the I/O port of the robot, and the user can turn on/off from the remote place.

And a small LED tip is attached on the cleaning head of the robot. This LED is also connected with the I/O port of the robot's controller, and it used to make the robot easy to find from the ceiling camera for estimating its correct position.

3.2 Ceiling Camera

We adapted a Panasonic web camera (KX-HCM1) as ceiling camera. This camera has motion JPEG transmission function by the HTTP protocol. Therefore, when outside PC accesses the camera according to the socket communication, the image is continuously obtained. The image transmission to the user interface has been achieved by the streaming function of this camera. The camera was fixed to the ceiling of our laboratory room at a height of 2m above the ground.

4. PATH INDICATION

4.1 User Interface

The interface was made by GTK+. It is based on a basic strategy in which an appropriate robot motion can be easily specified by selecting a position in an image displayed on a screen, and clicking mouse buttons. Clicked coordinates are stored in an array.

The lines which connect clicked positions are drawn in the displayed image. These lines represent the path the robot has to run. Finally, if the cleaning execution button is pushed, the operation is completed. The clicked coordinates group is forwarded to the robot.

4.2 Geometric transformation

To make the robot understand the cleaning route, it is necessary to convert coordinates of the clicked image into the corresponding floor coordinates.

Because of lens influence of the camera, images are slightly distorted. If distortion correction is performed to all images from the stream, processing time would increase. To avoid this, only images that are clicked to send coordinates are corrected using Matlab !G Camera Calibration Toolbox.

The following equation was used to convert image coordinate into real-floor coordinate.

$$\begin{pmatrix} Xw \\ Yw \end{pmatrix} = \begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \end{pmatrix} \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} \quad (1)$$

In order to determine and select equation parameters, we used a sheet on the floor as shown on Fig. 6. The sheet has a grid made of points on it. Images of the grid were taken from the ceiling camera and each point was clicked (for this purpose 29 points were marked), then according to method explained in this subsection, screen coordinates (u,v) were acquired. ! ! These parameters were introduced in equation (1). Then finally Least Square Method was used to determine the values of P11 to P23.

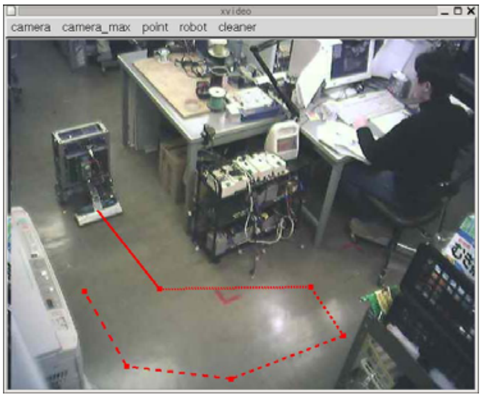


Fig. 5 Example of selecting a cleaning path using mouse

Fig. 6 Grid sheet used for finding coordinate transformation parameters by least square method

The accuracy of coordinate transformation was evaluated. Method and conditions are mentioned as follows:

- Experiments were performed at our laboratory room at University of Tsukuba room 3D402.
- 9 points of sheet shown at Fig.6 were clicked randomly.
- Camera was placed at the ceiling at a height of approximately 2m.

Results are shown at table 1. Screen coordinates represented by (u, v) and floor surface coordinates by (Xw, Yw). In table, (x, y) and !"(Xw, Yw) units are millimeters and (v, u) are given in pixels.

As results indicate, we had a maximum error of around 100mm, however, as almost all errors were within 50mm we could say that our coordinate transformation is accurate enough according to the size of our mobile robot. We could also confirm that image distortion correction was an important factor to improve accuracy of coordinate transformation due to the 10 pixels of correction it provided.

Moreover, it could be expected that if the surface work area where the operator has access expands and the number of points that are clicked by user increases, least square method transformation results could improve.

Points Clicked (x, y)	Surface Coord. (Xw, Yw)	Image Coord. (v, u)
(-300,-300)	(-247,-238)	(16,192)
(1200,-300)	(1205,-380)	(151,446)
(0,0)	(25,23)	(106,213)
(900,0)	(837,-13)	(191,351)
(300,300)	(285,282)	(194,232)
(1200,300)	(1176,290)	(298,379)
(1500,600)	(1508,614)	(409,404)
(1500,900)	(1475,899)	(469,372)
(1200,1200)	(1130,1102)	(475,296)

Table 1 Coordinate Transformation Accuracy Results !JUnits of (x, y) and (Xw, Yw) are mm!"and (v, u) in pixels!K

4.3 Running Instruction

The data points that were selected by user are sequentially stored and passed to the robot. This system loads point information one by one and moves from one point to another using a straight line command joining these two points. When the robot reaches within 30cm of the goal point, it loads the next goal point and executes a straight line path to the next point. This process is repeated until all points from database are loaded.

5. POSITION ESTIMATION

Odometry has the disadvantage that it has an unbounded accumulation of errors caused by slip or small errors in the robot. As the distance the robot travels increase, localization error increases proportionally. If the positioning of the robot is not correct, then it can not run and clean the selected path accurately. For these reasons a periodically position correction method is required [2].

Most mobile robots have its own sensors and measure its environment, however, in our case, the robot only possesses a small LED which can be detected and tracked by the camera placed on the ceiling. In this system, robot after running certain distance, it stops and the LED on it starts blinking several times. LED light is extracted taking image difference from two different consecutive images taken from ceiling camera. Fig. 7 shows an example of LED extraction using image difference. The LED position on surfaces coordinates is calculated using coordinate transformation method explained previously. Using this calculated position, robot position is corrected. As it was said in subsection 4.2 there is an error of about 50mm after coordinate transformation, however, by applying this method odometry accumulated errors can be canceled.

Odometry position information is corrected using the position estimated by the camera on the ceiling. As it is shown in Fig.8, as robot runs forward, because of odom-

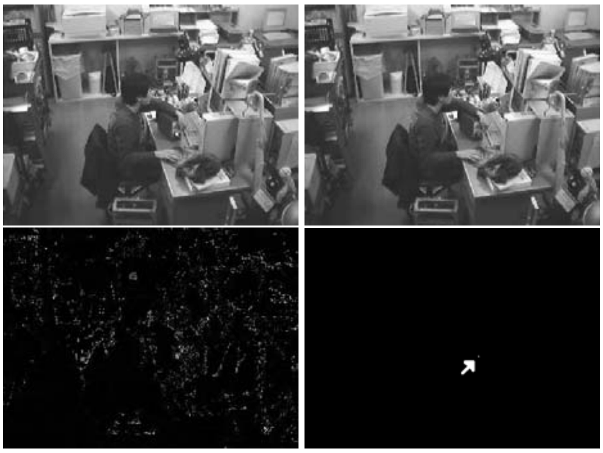


Fig. 7 Difference taken when LED is on and off!JUpper left: LED On, Upper right: LED off, Down left: Differential image, Down right: Extractive LED!K

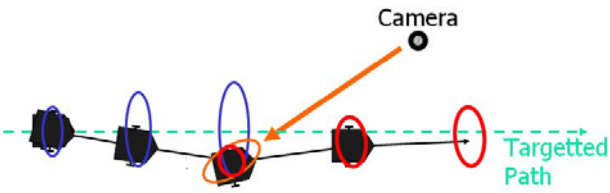


Fig. 8 Method of Position correction.

etry nature, position error distribution increases (blue ellipse). During robot running, camera detects and tracks the LED on the robot and uses that information to determine robot position (orange ellipse). These two position estimates are fused and result in a more reliable position and posture estimation (red ellipse). Using this method, robot can navigate in complicated indoor environments during long periods of time performing room cleaning function.

6. EXPERIMENTS

Experiments were conducted to evaluate this cleaning robot system in indoor environments. Appearance before cleaning is shown in Fig.9(a). Dust can be seen on the floor before cleaning. At this time, the user sequentially clicked dust positions.

Fig.9(b) shows room appearance after the robot cleans this area. Dust on the floor was completely removed.

7. SUMMARY

In this research, a house cleaning robot system in which the user with a PC interface selects the cleaning paths, was developed. This system can achieve efficient cleaning without useless robot motions. Moreover, the probable position of the robot was determined by observing LED from the ceiling camera, and long time cleaning

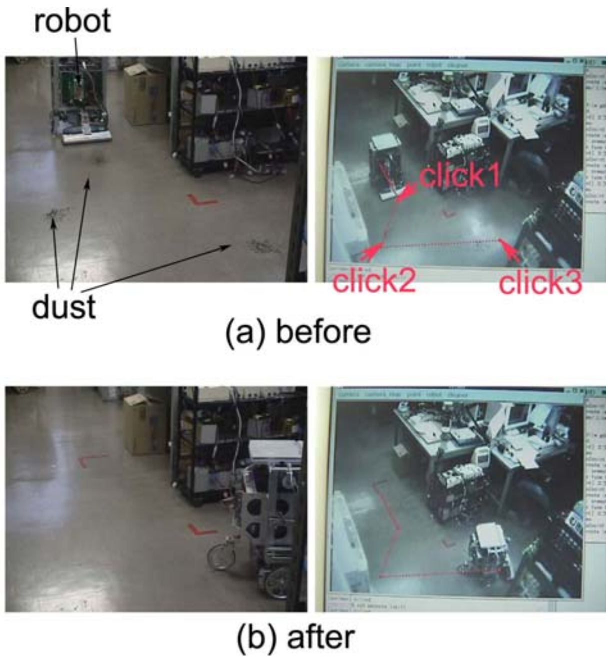


Fig. 9 Scenes of an experiment.

was achieved.

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