Development of an indoor mobile robot for AGV

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Abstract

This paper presents the development of a mobile robot for the autonomous AGV(Automated Guided Vehicle) which has no external guiding systems and navigates by vision. We chose indoor environments for the autonomous AGV and the environment was modified according to their structural complexity and artificial landmarks were used to modify the environments. Lower level functions which are generally important for the mobile robot should be realized at the first stage of the robot development. Those functions are detecting navigable areas coping with the disturbances mainly caused by illuminating conditions and generating trajectories avoiding stationary obstacles. In conclusion these functions enable our robot to be used as an autonomous AGV under modified conditions.

1. Introduction

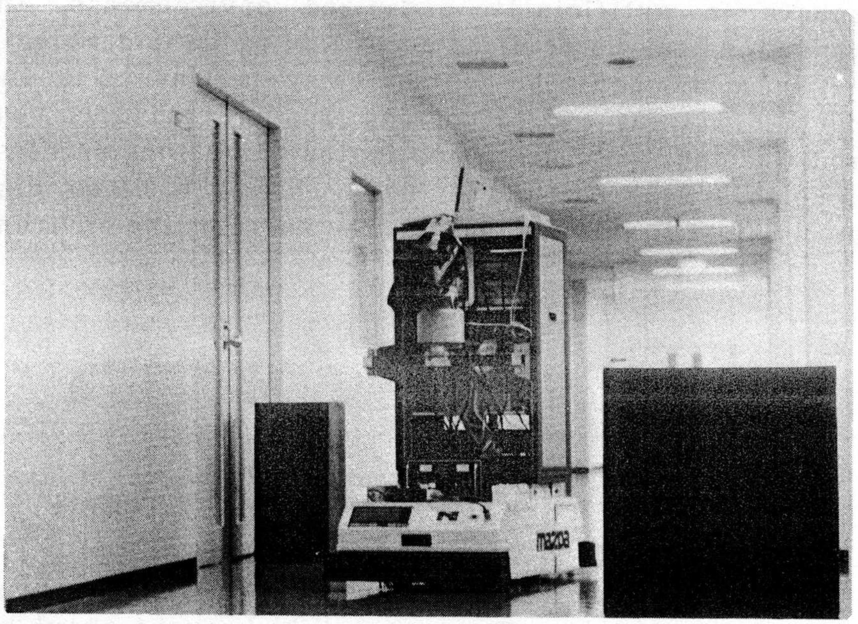
Fig. 1 MOVER 0

We have developed an experimental mobile robot MOVER 0 (Fig. 1), short for MObile Vision Experimental Robot 0. This autonomous mobile robot is used as a tool for basic research on lower level mobile robot functions.

For mobile robots, various kinds of functions are necessary. They include lower level functions such as detecting navigable areas and obstacles and higher level functions such as understanding the structure of environments or route planning. Though the higher level functions are specified by the environments in which robots exist, the lower level functions are rather common to any mobile robot. So they are universal and with them, mobile robots can navigate under limited environmental conditions. Also they are practically applied to mobile robots which navigate under limited conditions such as AGVs.

We have chosen indoor environments which have disturbances caused by illuminating conditions and stationary obstacles. Under these conditions, the lower level functions of robust and real-time image processing and trajectory generation must be confirmed in order that the system can be easily applied to autonomous AGVs which have no external guiding systems[1].

2. Environment of navigation

At the first stage, we have chosen our research center for the robot's navigation. Because the indoor environment at the center mostly consists of rooms and corridors. It provides a typical indoor environment. Therefore, the system developed there can be applied to similar environments without much alteration.

The most fundamental function for indoor navigation is to detect navigable areas and generate trajectories. In some indoor environments, to detect navigable area is difficult because of the complexity of environmental structures. Since we plan to use mobile robots in artificially organized environments, the environmental conditions may be modified according to their complexity.

In rooms, paths are set by using continuous landmarks which define navigable areas and directions. Though corridors usually do not need modification, with some complicated conditions such as intersections of corridors, modification may be necessary. To do so, dispersed landmarks are employed, which represent the surrounding environments (Fig. 2).

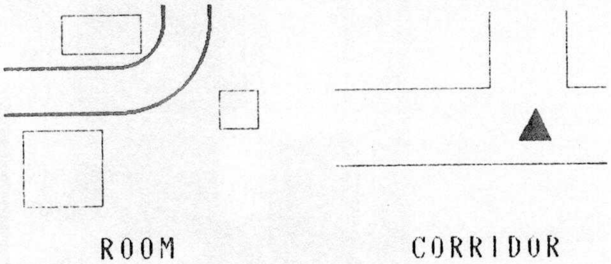

Fig. 2 Landmarks

Aside from environmental complexities, there are still disturbances to the robot vision. They are mainly brought about by the features of the floor and the illumination conditions.

The floors of the research center are covered with plastic tiles made of vinyl. In ordinary indoor environment, there are multiple illumination sources. The color of the illumination sources can be assumed the same. Though the brightness of the floor varies from place to place, the color of the floor does not change.
Since vinyl-tiles are dielectric material, there are many highlighted areas on the floors. Also there are shadows caused by objects situated on the floor.

3. System of MOVER 0

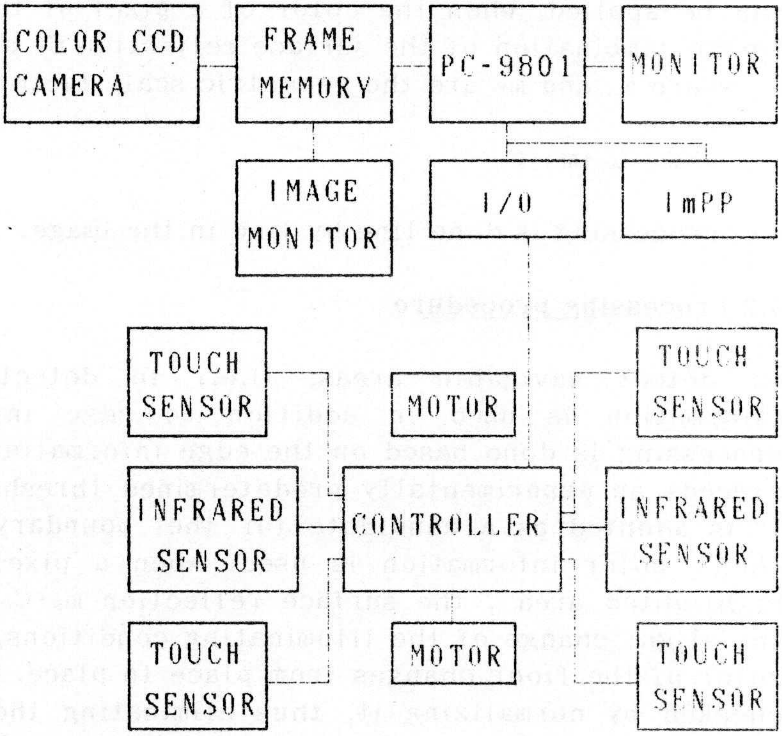

Fig. 3 Mobile robot system

The robot system was built on a cart driven by two DC motors (Fig. 3). The whole system is onboard and has no external connections and electricity is supplied to both the motors and the system by batteries loaded on the cart. The external environment of the robot is perceived by a single color CCD camera and taken into the image memory of a personal computer. The image memory has R, G, and B plane. The personal computer is an NEC 9801 and the CPU of the computer is an 80286 with a coprocessor 80287. This personal computer is the main computer of the system and its capability is sufficient for lower level functions excluding image processing. For image processing ImPPs (NEC μPD7281)[2] which are the Image Pipelined Processor with the data flow architecture were employed. The performance of an ImPP is 5 MIPS. As 4 ImPPs with a peripheral LSI MAGIC (NEC μPD9305) are used, the total performance is at most 20 MIPS.

The computer is also responsible for trajectory generation and operating motors. After processing a taken image, the main computer generates a trajectory. In case of emergencies, the robot is equipped with two infrared sensors, one at the front and the other at the rear, and touch sensors on the front and the rear bumpers. These sensors are used for emergency only and are not used for active sensing of the external environment.

4. Low level image processing

4.1 Processing strategy

Since vinyl is a dielectric material, the dichromatic reflection model[3] can be applied. When the color of a pixel of the floor is C, C is a linear combination of the surface reflection C_s and the body reflection C_b where m_s and m_b are the geometric scale factors.

$$C=m_s\cdot C_s+m_b\cdot C_b$$

The processing is done line by line in the image.

4.2 Processing procedure

To detect navigable areas, (i.e., to detect boundaries), color information is used in addition to edge information. First, the processing is done based on the edge information. When a edge's value exceeds an experimentally predetermined threshold level is detected, it is adopted as a candidate for the boundary of a navigable area. Then color information is used. When a pixel does not exist in a highlighted area , the surface reflection $m_s\cdot C_s$ is negligible. Due to the slight change of the illuminating conditions, the brightness of the color of the floor changes from place to place. So the color should be checked by normalizing it, thus eliminating the effect of m_b[4]. The original color of a pixel (R,G,B) is normalized into (r,g,b).

$$r=R/(R+G+B),\ g=G/(R+G+B),\ b=B/(R+G+B)$$

The normalized color is compared with the standard floor color . The standard floor color is the normalized average floor color. If the normalized color of the pixel does not stay close to the standard floor color, the boundary candidate is deemed a real boundary of the navigable area.

4.3 Other disturbances

The edge information is checked before the color information to avoid the influences of hilights and shadows on the floor. Because there are no or weak edges in transient area from matte area to highlighted or shadowed areas.

Since the robot can navigate while processing images near the robot, thus far, the robot does not have to cope with the reflected images on the floor.

In some parts of indoor environments, there are illumination sources with different colors. Usually one of them is much stronger than the other and the interaction does not have to be considered.

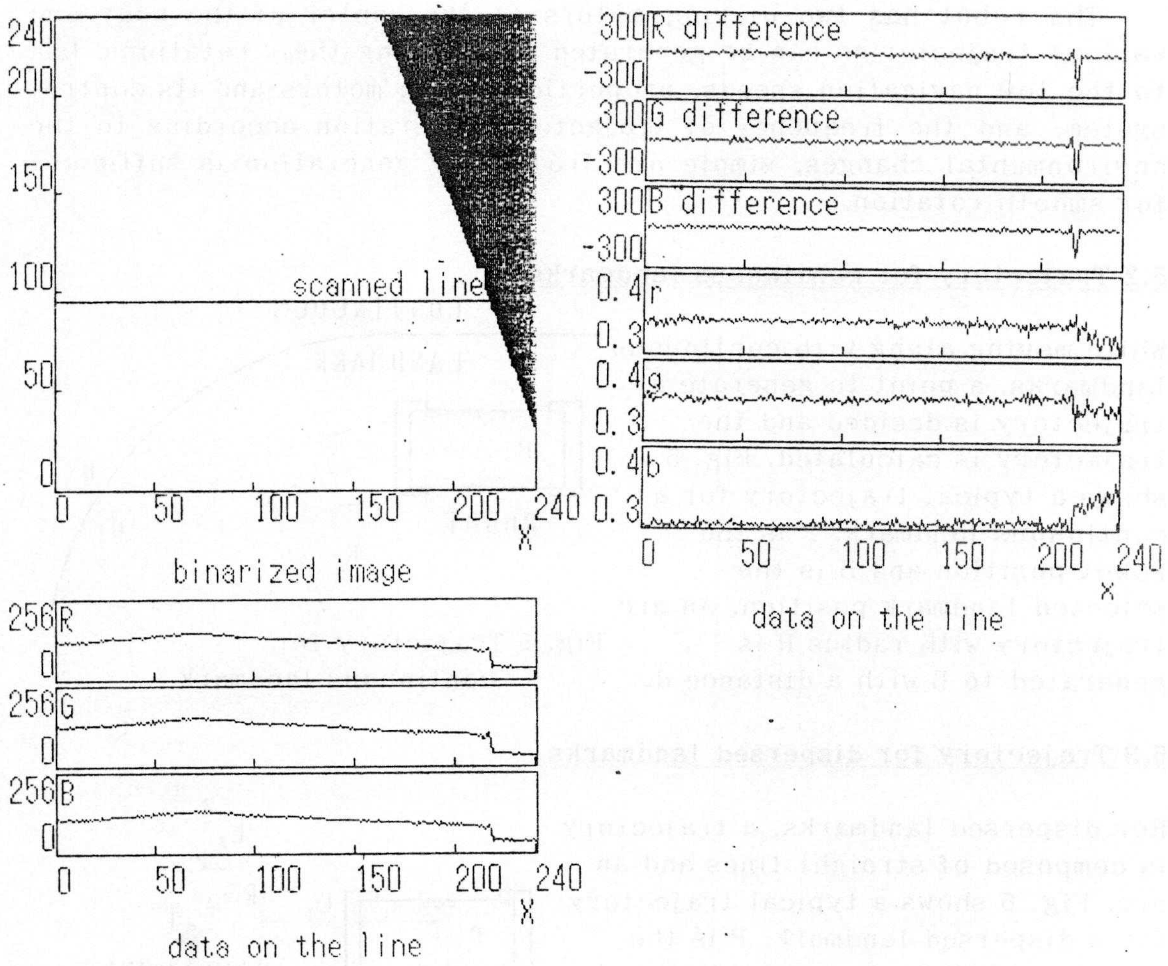

Fig.4 Processing along a line

4.4 Implementation

This process has been developed and implemented on the ImPPs. The important thing for the ImPP implementation is to keep their processing work loads even. Since the level of the processing at this stage is rather low, parallelism is easily realized by just splitting the processing load into even parts for each processor.

5. Trajectory generation

5.1 Trajectory generation with two motors

After processing the image and extracting the navigable area within a path with obstacles in the external world, the robot decides its behavior. The robot generates trajectories inside the navigable area.

The robot has two driving motors at the center of the body and various trajectories can be generated by altering their rotations. Due to the low navigation speeds, properties of the motors and its control system, and the frequency of trajectory generation according to the environmental changes, simple arc trajectory generation is sufficient for smooth rotation.

5.2 Trajectory for continuous landmarks

While moving along with continuous landmarks, a point to generate a trajectory is decided and the trajectory is calculated. Fig. 5 shows a typical trajectory for a continuous landmark. P is the robot position and B is the selected landmark position. An arc trajectory with radius R is generated to B with a distance d.

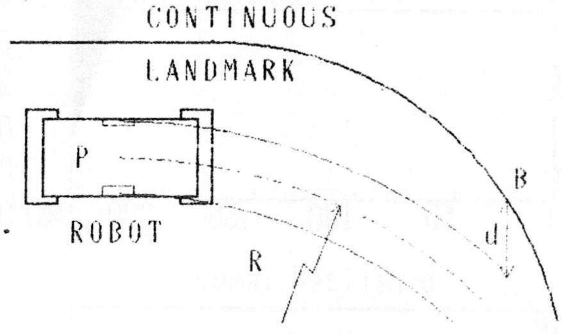

Fig. 5 Trajectory for continuous landmark

5.3 Trajectory for dispersed landmarks

For dispersed landmarks, a trajectory is composed of straight lines and an arc. Fig. 6 shows a typical trajectory for a dispersed landmark. P is the position of the robot and T is the position of a dispersed landmark. The length of the straight lines and the radius of the arc are determined according to the environment.

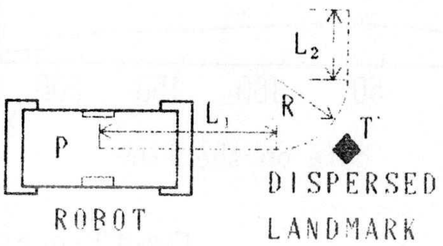

Fig. 6 Trajectory for dispersed landmarks

The robot may have difficulty extracting enough information from a distant dispersed landmark. In such cases, the robot approaches the landmark to perceive its correct shape.

5.4 Trajectory for stationary obstacles

When obstacles appear and the shape of the navigable area becomes complicated, fuzzy control is used. Fuzzy rules are decided based on our experience in walking indoors and altered by experiments. Fig. 7 shows an example of the rules. G is the center of gravity of the navigable area.

"If G is right
make a right turn."

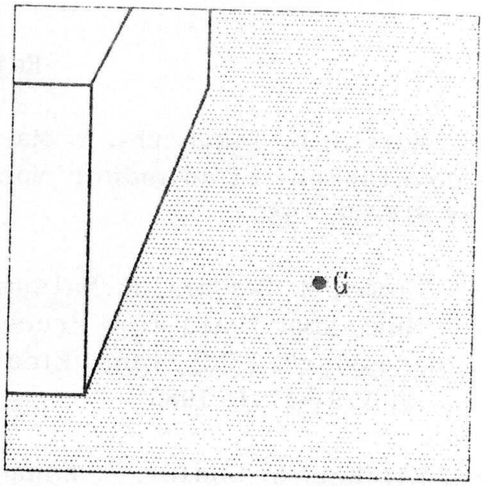

Fig.7 Fuzzy rule example

6. Experimental Results

The robot navigated successfully in the test environment which consisted of rooms and corridors with stationary obstacles. When the robot moved along continuous landmarks and the directions of the landmarks did not change drastically, the robot was able to run at a top speed of 2.5 km/h which is generally viewed as the sufficient maximum speed of autonomous AGVs. This speed was realized by using the ImPPs thus, we confirmed that the ImPPs are suitable for low level image processing. The illumination conditions of the environments were not modified for the robot and the robot did not fail to detect landmarks. Thus the image processing proved sufficiently robust for indoor navigation. Moving along obstacles, the robot generated trajectories smoothly avoiding collisions and the fuzzy control proved to be practical.

7. Summary

We have developed a mobile robot, MOVER 0, which navigates in indoor environments. The real-time and robust image processing, the trajectory generation using fuzzy rules proved effective enough for real world application.

We believe this system can be applied to the autonomous AGVs more extensively when the robot acquires the capability of avoiding moving obstacles such as people or vehicles in office buildings and plants. Our next target is to handle more general environments and to realize the capability to cope with moving obstacles.

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