Human Following Behavior of an Autonomous Mobile Robot Using Light-Emitting Device

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Abstract

The purpose of this study is to develop an autonomous mobile robot which can follow a human being. The robot with a camera looks at a human having a light-emitting device. The device consists of two LEDs. between two LEDs and the direction from the position of the LED on the captured image. Then the robot can follow the trajectory of the human. The points of this research are camera's pan and flashing LEDs on and off. In this paper, the method and the result of a primary experiments are presented.

1 Introduction

In recent years, mobile robots have become autonomous enough so that we have to think of their applications. We consider in this research how robots can render service by moving by themselves. Our aim is to develop a robot moving along with people so that it can support them in everyday life by interacting with humans. How robot can support human life has already been described in many researches [1-5], including welfare. Several concrete supporting applications can be considered, such as indoor and outdoor guidance and information supplying, accompanying or escorting people, or following humans while carrying heavy objects. In this paper, we first consider the pattern to be used for following people and report on the realization of a mobile robot capable of following a person.

2 Human following

In order to follow a human, a mobile robot needs to know the position of the person and must be able to determine its own path in order to follow his target.

2.1 Method used to detect human position

There are several ways for a robot to understand the position of a person. In this research, we equip the person with a light-emitting device and make the robot detect this device using a camera. In order to appreciate the distance to the human, we use two LEDs fixed on a stick. The person carries this device perpendicular to the ground (Fig.1). By taking an image of this device, the robot is able to know the distance to the human thanks to the interval between the two lights in the image. It can also appreciate the direction taken by the device by determining the distance between the lights and the central vertical axis of the image (Fig.2).

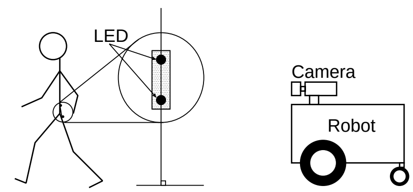

Figure 1: The robot follows the human using a camera.

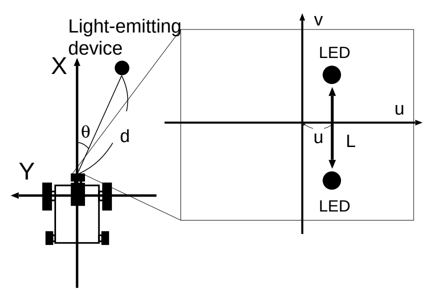

Figure 2: The schema of the image of LEDs obtained from camera mounted on the the robot.

2.2 Position of the light-emitting device in the image

We call L(pixel) the distance between the image of the two LEDs in the image and u(pixel) the distance between the image of the LEDS and the central vertical axis of the image. We note d the distance between the robot and the light-emitting device and θ the angle made between the X front side axis of the robot and the straight line connecting the camera and the device. X, θ, L and d are represented in Fig.2. The relation between L and d is given by equation (1) and it is possible to determine d while knowing L. a is a coefficient depending on the distance between the two LEDs.

$$d = a/L \tag{1}$$

The relation between the u coordinate of the LEDs in the image and θ is given by the linear function (2). b and c are coefficients depending on the direction of the robot and the device.

$$\theta = bu + c \tag{2}$$

We understand from above that if the relations between L and d, and X and θ are known, it is possible to determine the distance between the robot and the light-emitting device as well as the angle between them. We will use experimental results in order to estimate the invariant coefficients.

2.3 Determination of the path for human following

In order to prevent collision with obstacles, the robot should track the route followed by its target[5]. The approach used to make the robot move this way is as follows. The robot calculates the distance between the actual position of the device and the previous location of the device. If the distance the the device moved is greater than a value decided in advance, the position of the light-emitting device is recorded in a list. The robot reads each position recorded in the list successively and makes the appropriate movements to reach point (Fig.3).

In order to estimate its position, the vehicle uses odometry and computes the location of the light-emitting device relatively to the position of the vehicle. The location of the device is recorded by the robot in a global referential.

Moreover, the robot can adjusts its speed according to the number of points recorded in the list that exist between the actual pose of the vehicle and the location of the device. By doing so, the robot can track the path followed by its target.

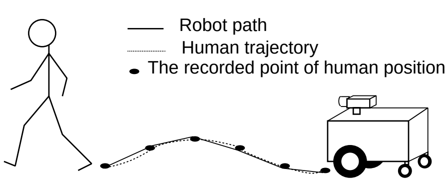

Figure 3: The position of the human is recorded at a moderate interval.

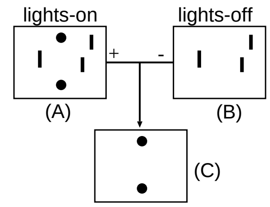

Figure 4: Difference image(C) obtained by subtracting lights-off image(B) from lights-on image(A).

3 Image processing method

3.1 Light-emitting device robust detection

In order to detect robustly the LEDs in the images taken by the robot, we make them turn on and off and take images of the light-emitting device when the lights are on and off. Then the difference of the two images is computed. As a result, pixels that don't correspond to the blinking LEDs have an intensity close to 0 and the location of the LEDs in the image can be obtained in a robust way (Fig.4).

Yet, it is difficult to take successive images exactly when the LEDs are on and off. The following approach is used to cope with this issue. First, the flash timing is set double to the frame rate of the camera which is 1/30 seconds. LEDs are on during 1/15 seconds and off during 1/15 seconds. Then four images are taken successively. By doing so, at least one image will contain the light-emitting device with the LEDs switched off, and at least one image will contain the light-emitting device with the LEDs switched on. By using the first and third, or the second and fourth images, it is possible to detect correctly the LEDs.

Fig.5 and Fig.6 illustrate how the LEDs can be detected in spite of the non-synchronization of the image capture and the LEDs blinking frequency.

3.2 The algorithm of detection LEDs

The LED detection algorithm is as follows.

(1) 4 pictures are captured.

(2) The first and third image are scanned from top to bottom and left to right in order to find a pixel

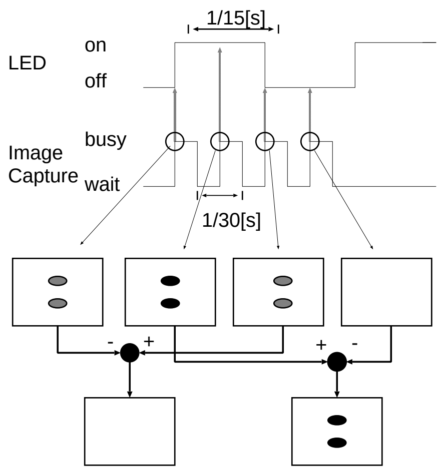

Figure 5: A good result is obtained when the second and fourth images are used.

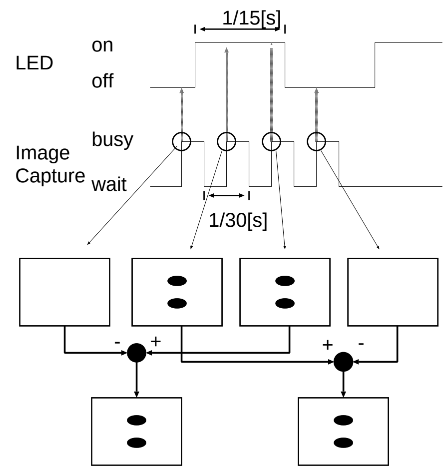

Figure 6: Both of pairs can generated good result in this case.

brighter than a given threshold(Fig.7). If nothing is found, the same operation is performed on the second and fourth images. In the case of nothing is found in images 2 and 4 as well, we go back to step 1.

(3) Since the second point should have an abscissa similar to the first one and a v coordinate greater than the first point, the search area is reduced as shown in Fig.8 If a second point is not found, we go back to step 1.

(4) After succeeding in finding two LEDs, the search area can be small.The search will be done in the region near the previous LED positions (Fig.9) after capturing new images. When the search is done successfully, we go back to step 4. Otherwise, go to step 2.

3.3 Increase of the recognition area through camera rotation

Since the field of view of a camera fixed on the robot is restricted, the light-emitting device may go out of the robot's field of view when the vehicle changes its direction in order to perform human following. As a result, following the target smoothly becomes a difficult task (Fig.10) It is therefore necessary to consider how to keep the image of the light-emitting device permanently in the field of view of the camera.

1. A wide-angle lens or an omni-directional camera can be used to enlarge the field of vision of the robot.

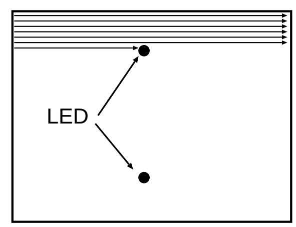

Figure 7: Search method for finding the first LED.

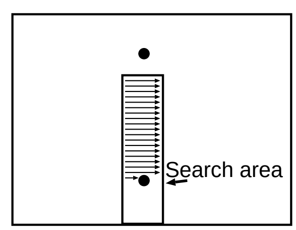

Figure 8: Search area for the second LED.

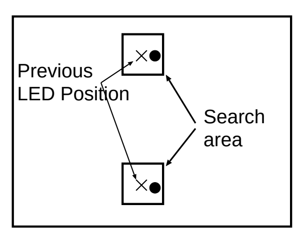

Figure 9: Search area when the previous search have been done successfully.

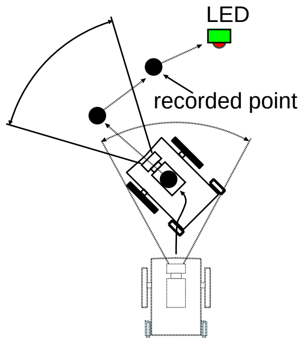

Figure 10: Missing LED when a fixed camera is turned by robot's rotation.

2. It is also possible to use several cameras pointing to different directions.

3. We can also try to maintain the light-emitting device into the field of view of the camera by making the camera turning on itself.

In this research, we provided the camera with one degree of freedom(pan). In the first approach, image resolution may not be enough whereas in the second one too complex image processing is involved.

The camera rotates in the following case. In order to keep the device in the field of vision of the camera, the camera rotates so that the LEDs are located in the center of the image. Since it is possible to know the orientation of the light-emitting device from the image taken by the camera, the camera has to rotate a value corresponding to this angle (Fig.11).

Moreover, when the robot is performing a following movement, it has to change its orientation, therefore, the camera is rotating together with the vehicle. In order to make the camera continue pointing in the direction of the light-emitting device, the camera is asked to keep pointing in the direction where the device was previously found.

The case when the light is out of sight of the camera must also be taken into account. In this case, the camera is rotating in order to find again the light-emitting device as follows. The camera is moving form +84till -84with an increment of 28until it finds the device again (Fig.12). The increment value corresponds to the visibility angle of the camera we used.

4 Experimental system

As a first step, we only consider human following in an indoor environment, an equipped a mobile robot designed for indoor experiments with the necessary functions to achieve human following.

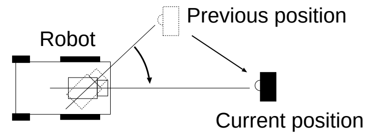

Figure 11: The camera location according to the light-emitting device.

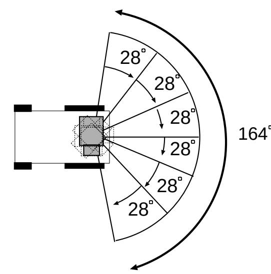

Figure 12: The behavior for finding a target.

4.1 Light-emitting device

The experimental light-emitting device is shown in Fig.13. Since LEDs are blinking, we are using infrared LEDs in order to avoid disturbing people. In order to prevent the light intensity from decreasing when the orientation of the light-emitting device changes, four LEDs were grouped together on each extremity of the light-emitting device. A zoom on one of the two 4 LEDs set is shown in Fig.14 and a picture of a person carrying the light-emitting device on its waist is given

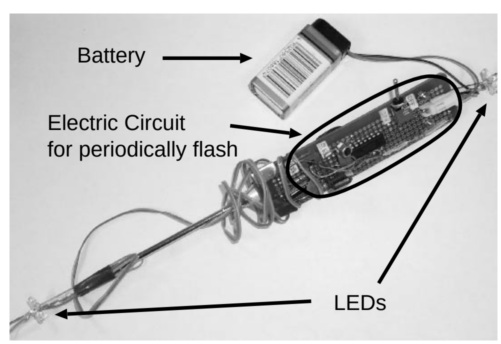

Figure 13: Light-emitting device used in the experiment.

Figure 14: A set of 4 LEDs for direction invariant emission.

Figure 15: A person carring the light-emitting device on its waist.

in Fig.15.The robot can detect the device accurately as long as the human keeps a natural walk.

In this research, the distance between the robot and the human in supposed to be between 0 and 3 meters. The farther the human target gets from the person, an error of one pixel is accumulating. Because of that, precision of the picture which is taken in near the 3m should have been thought ,in this research the 2pixel changing, in order for the distance which changes to be below the 10cm, it decided. So when it does, distance between the LED becomes the 24cm. Therefore, the device becomes length of approximately 24cm.

4.2 The robot

The platform used for this experiment is a mobile robot shown in the Fig.16. which has been designed in

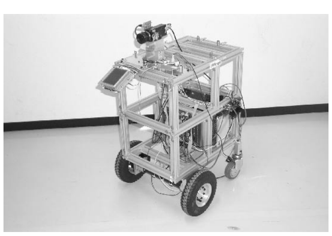

Figure 16: The mobile robot developed for this study.

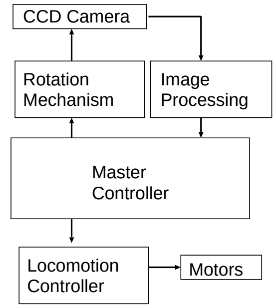

Figure 17: System structure of the robot.

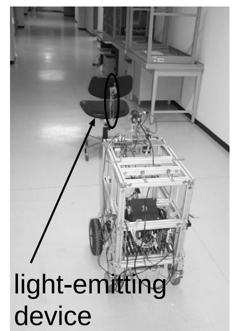

Figure 18: Experimental environment.

the purpose of this research. A CCD camera having one degree of freedom (pan) is installed on the top of the robot. Since infrared LEDs are used on the light-emitting device, a cut-off filter was installed on the camera. In order to increase the precision of distance estimation, the camera was mounted on its side on the robot so that the captured image is 240 pixels width and 768 pixels height. The system structure of this robot is shown in the Fig.17

5 Target following experiment

Experiments based on the method described above were done in the corridor of one of the buildings of the University of Tsukuba. In a first step, the light-emitting device was fixed on a wheeled chair which was moved according to a given path. The path followed by the light-emitting device was compared to the points the device passed recorded by the robot. The experimental environment is shown in Fig.18, and experimental results are given in Fig.19.

These results prove that basic following movement is realizable. In a second step, the light-emitting device was carried by a person and the robot had to follow it. The robot could track the path followed by the human target. Figure 20 represents different steps of this experiment.

6 Conclusion

In this paper, we presented a method to achieve human following as a first step toward the development of a robot moving along with a person. As a future work, it should be done to verified how robust this detecting LEDs method is and to cope with situations when the robot can not detect light-emitting device. We are also planning to make experiments using laser range sensor, omnidirectional optical sensor as well as ultra-sonic transponder. Furthermore, we are planning to add a function enabling a two-way oral communication for human interaction as well as enabling the robot to understand people's aims and to provide them information. Once the stage of building a clever robot capable of moving along with humans will have been achieved, we will consider lastly the relation between human and intelligent robot interaction.

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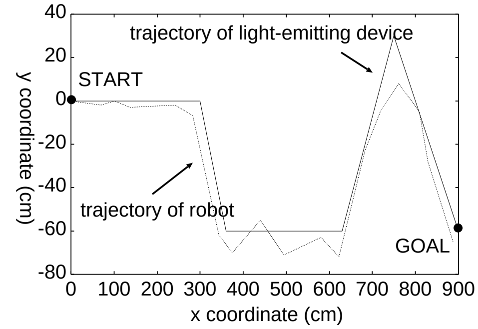

Figure 19: Experimental result of target following.

Figure 20: Human following behavior.