Person following with obstacle avoidance based on multi-layered mean shift and force field method

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Abstract—The paper presents the person following method with obstacle avoidance. The robot is equipped with RGB camera and laser range finder. The method is based on the target person tracking using multi-layered mean shift and three force fields based obstacle avoidance. To validate the method, we applied this method on the robot platform. The experimental result and analysis are presented in the experiment.

Keywords—person following, obstacle avoidance, mean shift

I. INTRODUCTION

Person following is essential technique for human robot interaction. The robot with this capability can provide user friendly service or other assistances for users. Some researchers developed the person following on the successful robot platform for goals such as museum guidance robot, hospital assistance, or nursing home [1][2][3]. Nowadays some researchers have developed person following algorithm using omnidirectional camera and laser range finder in outdoor environments [4]. Other researchers developed an online mean-shift object tracking algorithm using discrete and real adaboost techniques [5]. In the real environment, the person can move faster than robot following and the obstacles can intervene between target person and the following robot. In this case, the robot should avoid obstacles and follow the target person, again.

In this paper, we present person following with obstacle avoidance using a camera and laser range finder. Figure 1 shows the example scenes of the robot avoiding obstacles and following the target person. The method is composed of three steps. The first step is detecting and tracking the target person on the image. The main algorithm for tracking is mean shift using multi-layered histogram back projection. The next step is making the obstacle force field using laser range finder data. The final step is making the steering force field using information of target person on the image and composing the integrated force field using steering force field and obstacle force field. The main contribution of this paper is developing the system and applied in the real environment. This paper is composed of as follows. In section 2, we present the robot platform and the approach. Then we illustrate experimental results and analysis in section 3. Section 4 concludes this paper.

II. APPROACH

A. Robot platform

We implemented the proposed method on our research platform, POMI (Penguin Robot for Multi-modal Interaction), as shown in Figure 2. The RGB camera, Pixim ambient light rejection camera, is equipped on the head with 70 cm height. The camera can self-adjust for lighting conditions. URG laser range finder by Hokuyo is equipped near the wheel. The robot can rotate the head from -30 degree to 30 degree to track the target efficiently. The robot can move at speeds of up to 80cm/sec, but we limit the speed with 40cm/sec due to the stability and safety concerns.

B. Person tracking

For tracking the target person, we used the color based mean shift tracking method because of its simplicity and efficiency [6]. The popular feature space for the color based mean shift tracking is color histogram back projection [7]. However ordinary mean shift using color histogram back projection has difficulty in tracking the object having multiple
colors. The major drawback of histogram back projection is not able to represent the multiple colors of the object. To overcome this drawback, we devised mean shift using multi-layered histogram back projection. The mean shift using multi-layered histogram back projection can hold and utilize the structural information and multiple color information of the target person. We divide the target person into three parts; head, upper body, and lower body. We composed three layered histogram back projection as these parts in Figure 3. In the multi-layered histogram back projection scheme, each layer represents single distinctive color information of the target object, respectively. In the mean shift, the target object is represented with multiple histogram back projection. Then the target object is tracked using the modified mean shift. The process is described in the below. The whole process is similar with ordinary mean shift using single layered histogram back projection.

![Figure 3. The registered parts (left and center) and its histogram back projection (right).](image)

- Step 1. Divide the target object into N parts with single color.
- Step 2. Compute the center \((c_{x_i}, c_{y_i})\) of the \(i\) th part for \(i = 1 \ldots N\).
- Step 3. Set the neighborhood of the center point as a candidate region.
- Step 4. Compute the weighted mean in the candidate region on each feature space of histogram back projection. Let \(w_k\) be weight at \(k\) and \(R_i\) be the candidate region of the \(i\) th part.
  
  \[
  c_{x_i} = \sum_{k \in R_i} w_k x_k / \sum_{k \in R_i} w_k ,
  \]
  
  \[
  c_{y_i} = \sum_{k \in R_i} w_k y_k / \sum_{k \in R_i} w_k .
  \]
- Step 5. Calculate the movement of the center point of each part and aggregate them.
  
  \[
  dx_i = c_{x_i}^{\text{new}} - c_{x_i}^{\text{old}} ,
  \]
  
  \[
  dy_i = c_{y_i}^{\text{new}} - c_{y_i}^{\text{old}} ,
  \]
  
  for \(i = 1 \ldots N\).
  
  \[
  dx_{\text{total}} = \sum_{i=1}^{N} dx_i / N ,
  \]
  
  \[
  dy_{\text{total}} = \sum_{i=1}^{N} dy_i / N .
  \]
- Step 6. Update the center of the objects using the total movement \((dx_{\text{total}}, dy_{\text{total}})\).
  
  \[
  c_{x_i}^{\text{new}} = c_{x_i}^{\text{old}} + dx_{\text{total}} ,
  \]
  
  \[
  c_{y_i}^{\text{new}} = c_{y_i}^{\text{old}} + dy_{\text{total}} ,
  \]
  
  for \(i = 1 \ldots N\).
- Step 7. Repeat the process step 3 ~ 6 until converging.

After the mean shift, we try to detect the face and omega shape to re-register and update the mean shift model. This step guarantees the robustness of the system. In this step, we used the adaboost based face and omega shape detector [8].

C. Obstacle avoidance

We applied the obstacle avoidance algorithm using laser range finder (LRF) [9]. The obstacle avoidance algorithm we used is combined version of the potential field method (PFM) [10] and the vector field histogram (VFH) [11]. We overcame the hardware limitation (the absence of mobile encoders) using this method. The method is composed of three force fields. The steering force field is generated from the steering command by a user. The steering force field has the highest value on the target angle. The second force field, obstacle force field, was generated from LRF. Using the distances acquired from LRF, the obstacle field has the highest value at the angles with no obstacles and lower value at the angle where obstacles were detected. The final force field, integrated force field, is weighted combination form of previous two force fields. The example fields were displayed in Figure 4. The detailed process of generating these force fields is described in [9].

![Figure 4. Obstacle force field (left), steering force field (center), and integrated force field (right).](image)

D. Person following

We developed the person following system with previous modules and connected to motor control. The overall process of person following is in Figure 5. In the initial state, the system registers the colors of three parts (face, upper body, and lower body) of the target person for mean shift. In the tracking and following state, the system gets an image and LRF data. From the image, system tracks the target person using mean shift with multi-layered histogram back projection. The system updates the information of the target person if the face and omega shape is detected in the candidate region including tracking result. The steering force field is made using the target angle of the target object tracked. Also, the obstacle force field
is generated using LRF data. Then the system compensates the angle of steering force field because the head with a camera can be rotated for the target object. After the compensation of the head rotation, steering force field and obstacle force field are fused into integrated force field. Using this field, the system finds the angle with maximum value. The velocity of the robot is controlled by the y-position of the head of the target person. If the y-position of the target is above the predefined threshold, it means the target is near than predefined distance. Otherwise, if the y-position of the target is below the predefined threshold, it means the target is far than predefined distance.

III. EXPERIMENT

A. Procedure

We present the results of the person following from several trial runs. All trials took place in the space similar with home. We used monitors, desks, and other robots as the obstacles. The speed of the robot was limited to 40 cm/sec for safety and stability of the hardware. The system performed the following process with 4 ~ 8 frame per second.

B. Results

Figure 6 shows the tracking and force fields results of two trials in several trials. The other trials show similar results with these results. The left column shows the results of mean shift tracking using multi-layered histogram. Three rectangles show the tracking result of three parts. Even though background has similar color with the upper clothes of the target person, the system tracks the target person robustly in Figure 6. The center column shows face and omega shape...
detection results. The rectangle with red color means the each detection module detects faces or omega shapes. The right column shows the final direction (black arrow), LRF data (pink) and three force fields; obstacle force field (red), steering force field (green), and integrated force field (blue). When there is obstacle between the robot and the target person, steering force field has the highest value at the angle near an obstacle. However obstacle force field reduces the value and the integrated force field presents the direction to avoid the obstacle and follow the target person.

Figure 7. The results of tracking (left), face/omega detection (center), and three force fields (right).

IV. CONCLUSION

This paper presents the person following system with obstacle avoidance. The system used novel mean shift using multi-layered histogram back projection for tracking the target person and obstacle avoidance algorithm using three force fields. We showed the processing results and analysis in the experiment.

REFERENCES