Visual Feedback Interception of A Moving Ball by An Omni-Wheeled Mobile Robot with An On-Board Camera

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The manipulation task addressed in this paper is to intercept a moving ball by an omni-wheeled mobile robot with a single on-board camera. For this task, the authors present a control algorithm based on a visual feedback controller with a ball motion compensator. Experimental results demonstrate the effectiveness of the proposed control algorithm.

Keywords: omni-wheeled mobile robots, interception of a moving ball, visual feedback control, ball motion compensation

1. Introduction

In not only industrial factories but also home, autonomous mobile robots need abilities to understand their external environment. A camera is a nice sensor that provides a vision function to the robots. An image captured by the camera contains a vast amount of visual information for the environment. Using the information effectively in a control loop would enable robots work flexibly for a given task.

More dexterous manipulability for target objects are also required for autonomous mobile robots. It can be said that conventional object manipulation of a robot is static or quasi-static, which means that robots can grasp the object or can exploit a certain level of friction to stabilize the object. To achieve dynamic manipulation like human, the further advancement of nonprehensile manipulation is necessary rather than the one of prehensile manipulation. A recent literature [(1)] surveys many researches on nonprehensile manipulation.

The RoboCup Soccer Small Size League (SSL) provides a good field for advancing the above-mentioned studies. RoboCup is an international scientific initiative with the goal to advance the state of the art of intelligent robots [(2)]. In particular, the SSL focuses on fast-paced soccer games with actual omni-wheeled mobile robots. Their autonomous soccer games are maintained by a global vision system, wireless network, and a centralized system. There, however, is a problem that the game has to be interrupted if the global vision runs into any trouble; as taking the ultimate goal of RoboCup into account, it would be natural to shift the global vision system to a local one or to merge the global vision with a local one. Moreover, SSL-Vision Blackout Challenge [(3)] was held in the SSL of RoboCup 2019. In this technical challenge, only local vision can be used to detect the ball and to provide the information for controlling the robot.

This paper addresses a visual manipulation task of an omni-wheeled mobile robot with a single camera. In particular, the authors deal with visually intercepting a moving ball. To achieve this task, we present a visual feedback controller with a ball motion compensator. The effectiveness of the proposed controller is verified by experimental results.

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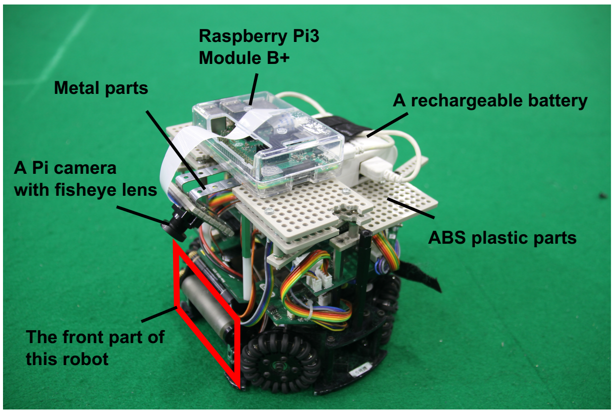


Fig. 1. An SSL robot with a local vision system

2. Setup of A Local Vision System

The SSL rules allow participators use local vision under some restriction, but almost all teams have not been used so far for the main soccer competition to the best of the authors' knowledge. Our local vision system is composed of a Raspberry Pi and a Pi camera module with fisheye lens. The camera with fisheye lens provides a wide field of view but has big distortion to the image. As shown in Fig. 1, the local vision system with a rechargeable battery is mounted on an omni-wheeled mobile robot without the cover.

On the local vision system, a series of image processing extracts an orange ball from a distortion-corrected image as a feature point (u, v). We cannot measure the depth z of the ball from an image of a single camera normally. We here calculate the estimated depth $\hat{z}$ by associating the area of the ball on the image plane with the actual depth z in advance. The obtained data of (u, v) and $\hat{z}$ are sent to a control PC by wireless communication in order to use them for controlling the robot.

3. A Control Algorithm for Visual Interception of A Moving Ball

Consider the following interception task which is same with the second challenge of SSL-Vision Blackout Challenge [(3)]:

> *Intercept a ball passing through an area within* 0.5 *m around a robot at a speed of* 6.5 *m/s or less, where the ball should be trapped by the front of the robot.*

For this task, we can design a controller mainly on the basis of image-based visual servoing [4]. Thanks to the camera mounting and the omni-directional motion (see Fig. 1), we can roughly associate the horizontal motion on the image plane with changing the robot's orientation (angle). Similarly, the vertical motion on the image plane can be associated with the robot's forwarding/backwarding. The use of this characteristic does not require a Jacobian matrix to derive a visual feedback controller. In order to achieve the given task, another point is to compensate ball motion on the image plane. Therefore, we propose the following control algorithm:

Step 1 Let $u^\star$ be the horizontal component (*i.e.*, the u-component) of the center coordinates on the image plane. Control the translational velocity of the robot's side direction v_y so that u converges to $u^\star$ by using the following equation:

$$v_y[i] = k_u(u[i] - u^\star) + k_{uc}(u[i] - u[i-1]), \quad (1)$$

where k_u and k_{uc} are tuning parameters, respectively.

Step 2 Stop the robot when the IR sensor responds.

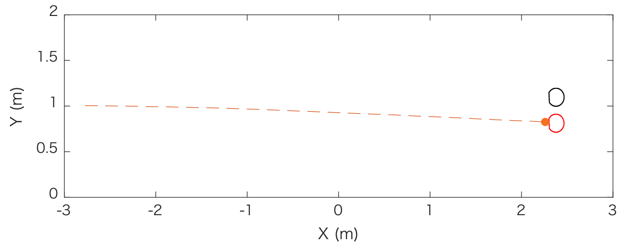
The difference between the conventional methods [5][6] and proposed method is as follows: the former is based on the geometric information of the target object in the 3D workspace and/or the robot joint variables; the latter is based only on the velocity of feature point on the image plane.

4. Experimental Verification

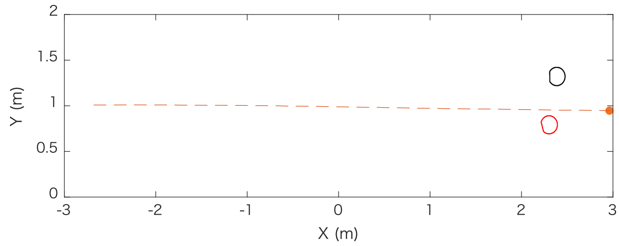
To verify the effectiveness of the proposed control algorithm, experiments were performed under the following conditions. There were a controlled robot and a ball. The distance between them was about 5 m. Another robot kicked the ball to pass the area within 0.5 m around the controlled robot. The initial velocity of the ball was about 6 m/s, and also the velocity when approaching the robot was about 4.2 m/s. The vision-based information of (u, v) and $\hat{z}$ was updated every 66.7 ms; The control period was 16.7 ms.

Figure 2 shows the experimental results with $k_u = 3.0$. The difference between Fig. 2 (a) and (b) is whether the ball motion compensation—the second term on the right-hand side of Eq. (1)—works or not. In each case, the controller drove the robot from the initial position (in black) to the final position (in red). The effectiveness of ball motion compensation is confirmed from Fig. 2. The motion compensation assisted the task. Note that the value of k_{uc} was switched according to the value of $\hat{z}$. The reason is that the motion compensation causes overshoot if the value of k_{uc} is too high when approaching the moving ball.

Note that the gap between the update period of the vision-based information and the control period is not taken into account. The control accuracy could be improved if the vision-based information are interpolated (or estimated) between the update times.



(a) with ball motion compensation ($k_{uc} = 0.3$ (if $\hat{z} < 0.5$ m), 5.0 (otherwise))



(b) without ball motion compensation ($k_{uc} = 0$)

Fig. 2. Experimental results

5. Concluding Remarks

The manipulation task addressed in this paper is to intercept a moving ball by using a single on-board camera of an omni-wheeled mobile robot. For this task, the authors have presented a control algorithm based on a visual feedback controller with a ball motion compensator. Experimental results demonstrated the effectiveness of the proposed control algorithm.

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