CHAPTER 25

MANIPULATION BALANCE CONTROL SYSTEM BY COMPUTER VISION TOOLS

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Nowadays, new functions for humanoid robots are required. One of these functions can be an application in which the robot is able to serve drinks or cups over a try. Therefore, the goal of this paper is to show a research related to waiter robots and settles the bases of manipulation balance. To accomplish a manipulation balance oriented to transported object tasks, the control system and equilibrium of the object over a tray has been developed. Normally, the movement features come from the position of the motors or the inertial sensors. However, the novelty of this control system is to obtain these characteristics by computer vision tools.

1 Introduction

Throughout history, human beings have dreamt about a machine able to help us with our daily obligations or even to do them by itself. This desire, added to the advances which are taking place during the last years in different fields of the robotic and the technology available, have leaded to the need of developing new applications for humanoid robots to help people in the accomplishment of different tasks. In hospitals, museums, or office buildings/department stores, where they perform janitorial services, deliver, educate, or entertain. (Jardon, 2006) (Kulyukin, 2005) (Engelberger, 1999).

At the Carlos III University of Madrid, the humanoid robotics group "RoboticsLab", we have started to develop an autonomous mobile humanoid robot, which should be inserted as assistance robot or a personal robot in an office or a workshop environment as a waiter robot. The main component of such a robot for handling objects is its hand which carries out a tray.

The goal of this research is to investigate in the area of compliant control of humanoid robots with focus on the design and execution of complex manipulation skills. In particular, we must address the important subject manipulation control based on computer vision control. In essence, it is described the following aims: waiter robot application, kinematic and dynamic model for service tasks, and manipulation balance oriented to object transport tasks.

To control the stability of drinks or cups over the tray, methods related to artificial vision have been used. The inclination angle will be obtained to detect if it is in an equilibrium position or otherwise, if the humanoid robot's arm should make a correction in the tray position to avoid the bottle falling.

2 Robot model for manipulation balance application

To achieve a good balance control, it is needed to model the behavior of the bottle or drinks over the tray. Therefore, as the linear inverted pendulum model (LIPM) is the one whose performance is nearest to the reality, it has been chosen (Fig. 1) (Bugmann, 2015). The robot's hand corresponds to the car of the LIPM, whereas the bottle is the inverted pendulum which we want to maintain stabilized. Therefore, it is important to develop a complex 3-D kinematics configuration with a special non-grasping device to keep the balance of the bottle over the tray (Balaguer et al., 2006).

$$(I + ml^2)\ddot{\theta} - mgl\theta = ml\ddot{x}$$
$$(M + m)\ddot{x} + b\dot{x} - ml\ddot{\theta} = u$$

From these equations of the LIPM model can be deduced that the information needed to control the inverted pendulum, among others, comes from the angular acceleration. Therefore, the angular position of the bottle in each moment will have to be obtained by computer vision.

The decision of using this pendulum model is due to large friction force between the bottle and tray, as far as there is a non-slip material in the tray, there will be no linear movement between the bottle and the tray. Only, rotational movements will be generated. Therefore, the main characteristic employed in the control algorithm to indicate its stability, will be focused on the variations of the rotation's angle of the bottle, as said before. In addition, we can disregard the viscosity in the mathematical pendulum model. This allows us to simplify further our model and thus, to reduce the computing load during the control of the bottle.

Since the bottle rests on a surface, the strategy of Zero Moment Point (ZMP) employed in Fig. 1, can be used to define its balance (Suleiman, 2011). With the projection of ZMP, which will be obtained by computer vision tools, the stability state can be established. If the ZMP has overtaken the bottle resting surface, this one will fall from the tray.

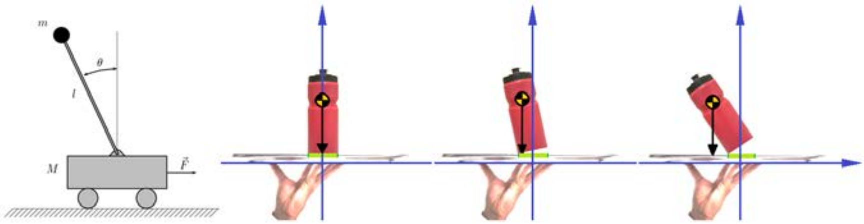

Fig. 1. Different degrees of stability applied to the linear inverted pendulum model.

3 Object characteristics obtained by computer vision

To accomplish the bottle balance by manipulation techniques following the LIPM, a wide range of features have to be obtained. These characteristics to close the control loop have been acquired mainly by computer vision. In this section, the way to obtain these features is explained.

To control the bottle equilibrium it is needed first to localize it in the space of the image, knowing the situation in which it is in each moment. The inclination angle will be also obtained, to detect if it is in an equilibrium position or otherwise if the humanoid robot must make a correction in the tray to avoid the bottle falling. Once the tilt angle has been acquired, the angular speed and the angular acceleration will be calculated. These properties will be the inputs to control the robot arm position, closing the feedback loop in order to achieve the bottle balance (Milighetti, 2011).

To localize the bottle in the image, after having differenced it from the other objects in the image, the geometrical center has been chosen based on a good reason: As it is geometrically symmetric, its center of mass is the same as its geometrical center. We also have to take in account that by computer vision we are not able to know the content inside the bottle, so we consider it is filled up with water having constant density. Therefore, we have an advantage in knowing each time the position in the image corresponding with both, the COM and the geometrical center of the bottle.

To obtain the inclination angle of the bottle (Fig. 1), based on experiments carried in (Cholewiak, 2015), in which the estimated future positions obtained by vision of an object in a non-equilibrium state, were related with the real position demonstrating that error committed was near to zero, have confirmed our choice of obtaining the inclination angle by computer vision. To achieve that aim, the bottle has been introduced in a rectangular box which comprehends the whole bottle. At the beginning it has been set as a totally straight position in which the value is 90 degrees, being zero degrees when the bottle is lying on the right side and 180 degrees when it is lying in the other side.

Finally, the angular speed and acceleration have been obtained. To obtain the speed we can use the optical flow and the histograms to estimate the speed and the disparity (Okada, 1996). However, to be able to calculate the angular speed and acceleration of the bottle in the image, it is needed to know an initial angle position, a final angle position and the time used to move from one position to the other one, as seen in next equations:

$$\omega = \lim_{\Delta t \to 0} \frac{\Delta \theta}{\Delta t} = \frac{d\theta}{dt} \qquad \alpha = \frac{\Delta \omega}{\Delta t} = \frac{\omega_1 - \omega_0}{t_1 - t_0}$$

A problem appears when we want to implement these equations by artificial vision techniques. As far as the data obtained are discrete, we have to work with this limitation and take in account that in the first iteration we will not have enough information. Since the second iteration, enough data from past and present position/speed will be available. With these values obtained and taking in account the time of this process we can obtain the angular speed/angular acceleration of the bottle (Fig. 2).

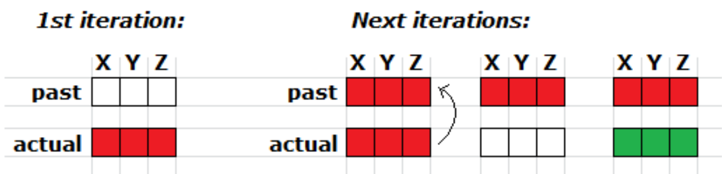

Fig. 2. Scheme for speed and acceleration discrete calculations.

4 Experiments performed

As the aim of this investigation is to set the bases for a service robot able to maintain the equilibrium of a bottle over a tray, is very important to evaluate the information obtained by computer vision techniques, to confirm that we have achieved a robust acquisition system. Therefore, several trials related to the bottle position and inclination have been performed.

First trials were made to acquire the position coordinates (x, y) of the geometrical center of the object among the image. As a result, a robust system to acquire the position of the bottle in the image has been obtained. This step was critical because its influence in the linear speed acquisition is high. From this point on, knowing the previous and the current position, linear velocity and acceleration have also been obtained.

The second experiment was related to the tilt angle of the bottle in relation to the horizontal plane. The program was configured in such a way that when the bottle was totally straight the bounding box appeared in a green color. When the bottle was bend no more than five degrees, the bounding box color is yellow (in this position, it still would be able to recover the equilibrium by its own weight), and lastly if this five degrees were overtaken, the bounding box changed its color to red meaning that the bottle was going to fall if corrective techniques were not applied. To set the inclination angle, the support surface and the position of the ZMP have been taken in account and the bottle has been modeled following the linear inverted pendulum model. We have to realize that once the ZMP has overtaken the support surface, the bottle is not any more in a position in which it can recover the equilibrium by itself without any external force.

After the acquisition of the tilt angle, we have obtained the angular position in each moment, allowing as calculating angular speed and acceleration. With this experiment we have confirmed that we are obtaining right the inclination angle of the bottle (Fig. 3).

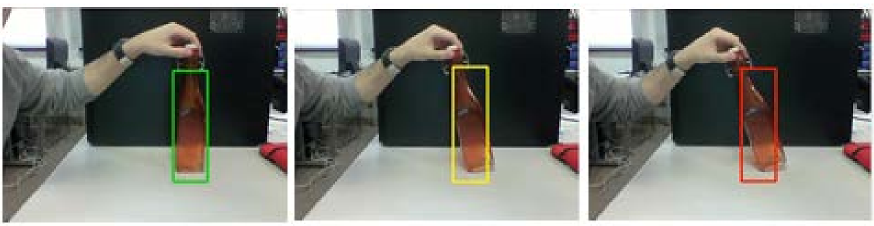

Fig. 3. Balance evaluation of the bottle applying to the LIMP model.

5 Future works

The experiments performed before, were developed with the aim of achieving a final complex system in which the humanoid robot is capable to assist people, by serving them drinks in a try. Therefore, the next step done in the research carried will be directed to reach a control system based on the position of the head in function of the direction of the movement of the bottle, in order to maintain through artificial vision techniques, the geometrical center of the bottle in the center of the image. The answer desired would be that once the bottle starts moving the robot also starts to move its head and to follow it (Fig. 4).

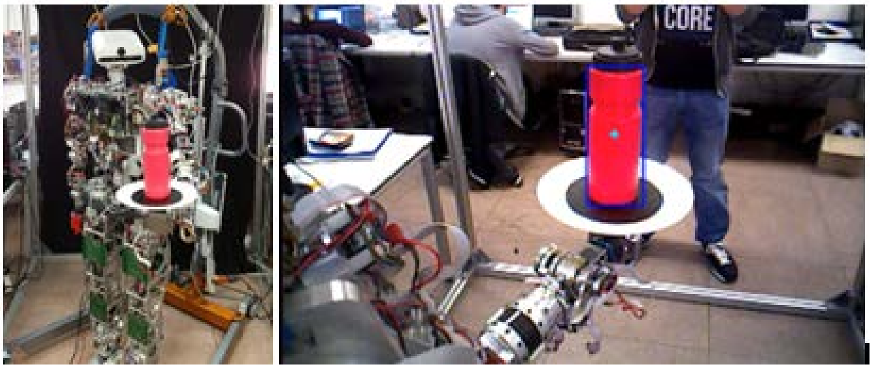

Fig. 4. Head movement to maintain the bottle centered in the image.

As the objective is to reach a full robust system, once the head control would be done, an arm position control will have to be integrated by using the angular speeds and accelerations obtained by computer vision, in order to rectify the tilt angle of the bottle and maintain it straight as a waiter would do to avoid the falling of the drinks over the tray.

Furthermore, once the bottle equilibrium over the tray has been achieved, an improvement in the application will be made in such a way that the arm can respond to an external stimulus such us a push force made for example by a human interaction, avoiding the falling of the bottle.

6 Conclusions

Manipulation tasks are not limited to grasping. There are manipulation applications in which physical interaction with objects is need but without grasping. The application exposed is one of them. The research performed is based on the knowledge from balance research and its application for maintaining equilibrium of an object on a tray. The visual perception has been used to determine the parameters related to the movement of the object and, then, compute the equilibrium indicators. Thanks to the use of a LIMP model balance control will be implemented based on visual information. The next step will be the integration with the manipulation controller in order to keep object balance through arm movement, counterbalancing any king of disturbance.

Acknowledgements

The research leading to these results has received funding from the RoboCity2030-III-CM project (Robótica aplicada a la mejora de la calidad de vida de los ciudadanos. Fase III; S2013/MIT-2748), funded by Programas de Actividades I+D en la Comunidad de Madrid and cofounded by Structural Funds of the EU.

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