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Advanced Technologies in Modern Robotic Applications

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Preface

Today's digital lifestyle is born from the revolutions of personal computer (PC) and Internet. Moving forward, it seems inevitable that robots will find their ways into our daily lives, integrating seamlessly into the fields of manufacturing, construction, household duties, services, medical operations, health care, etc. A new era of Industry 4.0 is coming, and robots will play significant roles in the new waves of technological revolutions. Unfortunately, most of the existing robot technologies are designed for traditional industrial applications for which the robots operate behind safeguarding and for predefined routine tasks, and thus are not able to perform varying tasks in unknown, complex, and dynamic environments. And modern robots are expected to co-habit with our humans and work closely with us in the fields such as manufacturing and health care as well as in other aspects of our daily lives, and are thus inevitably subject to unpredictable and uncertain external disturbances. Therefore, on the one side we focus on advanced control techniques for robots to deal with various uncertainties, and on the other side we pay much attention to visual servoing techniques which enable robot to autonomously operate in a dynamic environment.

In the recent decades, there is a significant trend in the robotic research community to develop advanced technologies that would enable robots to collaborate with humans friendly and naturally. Therefore, human–robot interaction is another important topic to be covered in this book. Much effort has been devoted to human–robot shared control in teleoperation, and advanced techniques involved in human–robot interfaces. Most of the techniques presented in this book have been tested by either simulations or experiments, preferably on human-like robot platforms such as Baxter robot, because humanoid robots are very popular and have been widely accepted by human users due to their appearances. In summary, the objective of this book is to present in a systematic manner the advanced technologies used for various modern robot applications. By bringing fresh ideas, new concepts, novel methods, and tools into robot control, human–robot interaction, robotic teleoperation, and multiple robot collaboration, we are to provide a state-of-the-art and comprehensive treatment of the advanced technologies for a wide range of robotic applications.

This book starts with an introduction to the robot platforms and tools used in this book in Chap. 1, including some popularly used humanoid robot platforms, visual sensors and haptic devices, and the simulation platforms such as MATLAB Robotics Toolbox, Virtual Robot Experiment Platform (V-REP) simulator, and Robot Operating System (ROS). Since robotic kinematics and dynamics are essential for describing the position, orientation, joints motion as well as analyzing and synthesizing the dynamic behavior of a robot, Chap. 2 discusses the robotic kinematics and dynamics modeling procedure of the commercialized Baxter robot and provides a case study of robot modeling. In Chap. 3, we introduce a number of novel intelligent control methods which are useful to deal with the uncertainties associated with the robot manipulators, such as model mismatch, changing of the external environment, and uncertain loads. These control methods include dual adaptive control, optimized model reference control, and discrete-time adaptive control. Machine vision and image processing are very important for advanced robots as they provide comprehensive and abundant information of surrounding environment. To realize the key functions for robots in understanding the surrounding environment, Chap. 4 focuses on vision-based object detection and tracking using pattern recognition and state estimation. And Chap. 5 investigates visual servoing based human–robot interaction which allows users just to perform in the front of the sensor devices without wearing or operating any control devices to achieve their control purposes. Human–robot collaboration is regarded as a key character of next generation robots which allows human and robot to interact physically with guaranteed safety and compliance. In Chap. 6, we investigate a number of robot teleoperation techniques which can be regarded as a straightforward way to achieve human–robot interaction, such as teleoperation using body motion tracking, teleoperation based on adaptive control approach and human–robot interaction using haptic feedback devices. These technologies are further investigated in Chap. 7, with establishment of a human–robot shared control framework in which the automatic obstacle avoidance can be achieved without affecting the intended teleoperation task. Chapter 8 studies several state-of-art techniques for human–robot interfaces, which are key elements for human–robot interactions, such as hand gesture based robot control, Emotiv neuroheadset in the controlling of mobile robot and the EEG signals based robot manipulator control. Robot localization is essential for a wide range of applications, such as navigation, autonomous vehicle, intrusion detection, and so on. Chapter 9 focuses on indoor/outdoor localization of robot, which is crucial for most tasks demanding accuracy. Chapter 10 is dedicated to the theoretical study of multiple robot cooperation in the framework of multi-agents system, including optimal multi-robot formation, hunting activities of a multi-robot system, and multi-robot cooperative lifting control. Finally, some useful technologies developed for other popular robot applications are presented in Chap. 11, including some theoretical and practical results of robot kicking, and reference trajectory adaptation algorithm for motion planning.

This book is featured with a number of attractive and original research studies, including the robot control design in a biomimetic manner, the teleoperation method in a human–robot shared control manner, the novel human–robot interaction interface based on hand gesture recognition and on electromyography (EMG). The publication of this book will systematically bring new knowledge created by the authors to the robotic communities, especially in the topics of biomimetic control, human–robot interaction and teleoperation. The book is primarily intended for researchers and engineers in the robotic and control community. It can also serve as complementary reading for robotics at both graduate and undergraduate levels. The book will help to consolidate knowledge and extend skills of robotic researchers. This book will be extremely useful for early career researchers to be equipped with a comprehensive knowledge of technologies in modern robot applications. This book will also bring fresh new ideas into education, and will benefit students by exposing them to the very forefront of robotics research; preparing them for possible future academic or industrial careers in robotics or robot applications.

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Chapter 1
Introduction of Robot Platforms and Relevant Tools

Abstract This chapter introduces a number of robot platforms and relevant devices used throughout this book, including the humanoid robot platforms such as Baxter robot and iCub robot; visual sensors of Microsoft Kinect, stereo camera Point Grey Bumblebee2 and 3D camera Leap Motion, as well as haptic devices of SensAble Omni and Novint joystick Falcon. Meanwhile, a number of software toolkits useful in robot simulation are also introduced in this chapter, e.g., the MATLAB Robotics Toolbox and the Virtual Robot Experiment Platform (V-REP) simulator. Robot Operating System (ROS) is also briefly introduced by highlighting the ROS characters and ROS level concepts. These devices and toolkits are nowadays becoming more and more popularly used in the study of robotics, as they provide ideal means for the study, design, and test of the robotic technologies.

1.1 Robot Platforms

1.1.1 Baxter® Robot

The increasing pace of introduction of new products, particularly those with many variants and short lifetimes, brings considerable uncertainty to assembly line design. It is therefore very desirable to develop flexible and reconfigurable manufacturing systems. In this context, the humanoid dual-arm Baxter robot with intrinsic safety (e.g., physical compliance created by spring in between driving motors and robot joints) has been developed. The Baxter® humanoid robot made by Rethink Robotics™ offers users an affordable platform with guaranteed safety for both academic and industrial applications. The platform provides the users a good opportunity to carry out research on dual-arm robot manipulation and vision-based control.

To enable compliance on the dual arms, the Baxter® robot is equipped with Series Elastic Actuator (SEA) instead of connecting the motor shaft directly to the joint (usually through a gearbox). The motor in a SEA is coupled to the joint through a spring, so that the torque generated by twist of spring, rather than the torque from the motor directly drives the link. This enables the robot to behave in a human-like elastic manner. Due to the elastic effect of the spring, the SEA will lead to improved shock

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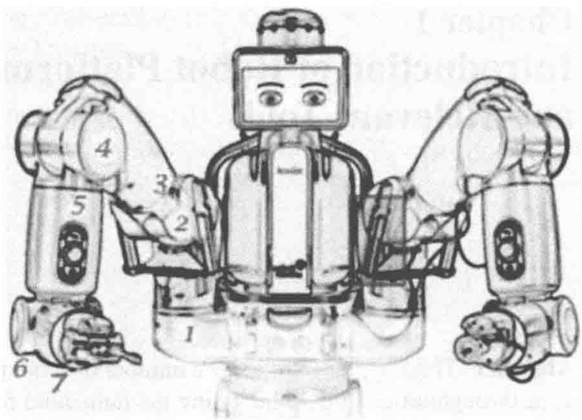

Fig. 1.1 Illustration of the Baxter robot, on which the joints *1, 2, 3* comprise the shoulder, *4 and 5* the elbow, and *6, 7* the wrist. The spring highlighted in *red*, two of which are attached to each arm, generate large forces to improve gravity compensation

tolerance and reduced danger in cases of collision. In addition, the Baxter® robot is able to sense a collision at a very early time instant before it hits badly onto a subject. Therefore, Baxter® robot is a good choice to fulfill safe human–robot interaction.

The Baxter® robot includes a torso based on a movable pedestal and two 7DOF (degree of freedom) arms installed on left/right arm mounts respectively. Each arm has 7 rotational joints and 8 links, as well as an interchangeable gripper (such as electric gripper or vacuum cup) which can be installed at the end of the arm. A head pan with a screen, located on the top of torso, can rotate in the horizontal plane [1].

One of the main features of Baxter is the Series Elastic Actuators (SEAs) which are present in every joint; these are comprised of a spring coupling between the motor and the link, with a built-in hall effect to measure the deflection. This creates a naturally compliant design, but also means that the torque at each joint can be easily estimated by measuring the spring deflection and multiplying by the known stiffness constant. There is also a gravity compensation controller running in a high-frequency loop, which calculates the torques required to counteract gravitational pull on each joint as well as the forces applied to joint 2 from the large external springs highlighted in Fig. 1.1. This is important to note, as the gravity compensation is applied by default, and must be manually disengaged for full torque control application.

1.1.2 iCub Robot

The iCub robot, as shown in Fig. 1.2, is a humanoid robot developed as part of an EU project "robotCub" and subsequently adopted by more than 20 laboratories worldwide. The height of iCub robot is 945 mm (from foot to head) and width of its lower torso is 176 mm (from left to right). The iCub robot has 53 motors that move the head, arms, hands, waist, and legs. The upper body of iCub robot comprises 38 joints: two 7 DOF arms, two 9 DoF hand, and a 6 DoF head. Each leg of the iCub

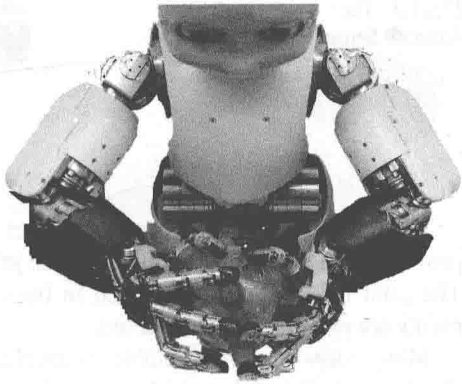

Fig. 1.2 The illustration of a iCub robot holding a ball

consists of 6 joints: three at the hip, one at the knee, and two at the ankle. A 3 DoF waist is installed at the body of iCub robot in order to enhance the workspace of the robot.

The main body of iCub robot is made by aluminum alloy, thus its weight strength ratio is outstanding. And it is appropriately used for highly and medium stressed parts, for example, actuator housing load-bearing parts, and so on. A cable-driven differential mechanism was chosen for iCub robot, in order to provide more stiffness on the hip joint for the implementation of its hip joint, especially for the flexion/extension and abduction/adduction motions of the hip joint.

In [2], the iCub robot is controlled to draw shapes after observing a demonstration by a teacher, by using a series of self-evaluations of its performance. In [3], a technique is proposed for controlling the interaction forces exploiting a proximal six axes force/torque sensor and is tested and validated on the iCub robot. One advantage of iCub robot is that it is an open-source cognitive robotic platform.

1.2 Visual Sensors and Haptic Devices

1.2.1 Microsoft Kinect Sensor

The Kinect sensor, as shown in Fig. 1.3, is a new hands-free and low-cost game controller interface introduced by Microsoft in 2010. It provides RGB video stream with 30 frames/s as well as a monochrome intensity encoded depth map, both in VGA resolution (640 × 480 pixels). The video offers 8-bit resolution while the depth data is represented in 11 bits in units of millimeters measured from the camera. The depth sensor is novel in the sense that it operates by projecting a known IR pattern onto the environment and measuring the returned IR pattern (using an IR camera). The received pattern is compared to the known projected pattern and the differences are used to extract object depth.

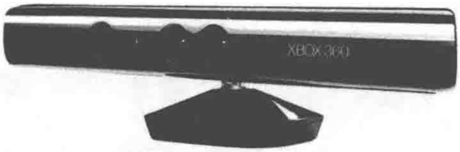

Fig. 1.3 The Kinect®.Sensor

Recently, in the new version of Kinect SDK, a skeletal tracking tool has been provided. This tool aims at collecting the joints as points relative to the device itself. The joint information is collected in frames. For each frame, the positions of 20 points are estimated and collected.

Many softwares are available to interface Kinect with PC, e.g., Libfreenect by OpenKinect, OpenNI, and Microsoft Kinect for windows SDK [4, 5]. OpenKinect is an open community of people interested in making use of the Kinect hardware with PCs and other devices. It releases software Libfreenect which can be used to interface Kinect along with any operating system in PC [4, 6]. OpenNI (open natural interaction) is similar software as Libfreenect [5]. OpenNI can support many other devices other than Kinect. It is open-source software released by Prime Sense, the company which manufactured Kinect for Microsoft. Apart from Kinect the company also manufactured many depth sensors. OpenNI uses middleware called NITE to get the skeleton data of the user [7]. Microsoft Kinect for windows SDK is another similar platform launched by Microsoft for windows systems [8]. SimpleOpenNI that uses OpenNI and NITE [7] is an OpenNI and NITE wrapper for processing. It may not support all the functions that are supported by OpenNI and NITE still, but most of the useful features can be accessed in a simple way [9, 10].

Kinect® is a motion sensing input device for Microsoft for Xbox 360 and Xbox One video game consoles and Windows PCs as shown in Fig. 1.3. It is basically a depth camera. Normal webcams collect light that is reflected by the objects in its field of view and turn them into digital signals, which are turned into an image. Kinect can also measure the distance between the objects and itself. A colored 3D point cloud can be generated from both of the RGB image and the depth image. Thus the Kinect® sensor can be used to detect the environment in front of it.

1.2.2 Point Grey Bumblebee2 Stereo Camera

The Point Grey Bumblebee2 stereo camera is a 2 sensor progressive scan CCD camera with fixed alignment between the sensors. Video is captured at a rate of 20 fps with a resolution of 640 $\times$ 480 to produce dense colored depth maps to assist in tracking and a viable pose estimation of the object. The resolution–speed trade-off has to be managed concisely as an increased frame speed gives a smooth robot trajectory, whereas enhances the processing time. And an increased resolution provides a denser, more accurate point cloud for feature extraction but with increased latency. Figure 1.4 shows the Bumblebee2 camera used in this book.

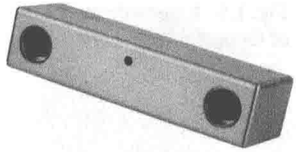

Fig. 1.4 The Point Grey Bumblebee2 camera. Reprinted from Ref. [11], with permission of Springer

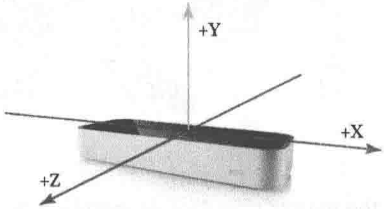

Fig. 1.5 Leap Motion Sensor. Reprinted from Ref. [13], with permission of Springer

1.2.3 Leap Motion Sensor

The Leap Motion sensor is equipped with two internal cameras to take photos from different directions to obtain hand action information in a 3D space. The detection range of Leap Motion is between 25 and 600 mm upon the sensor. The shape of the detection space is similar to an inverted cone [12]. Figure 1.5 depicts the coordinate system for the Leap Motion.

Recently, a method of remote interaction was put forward in [14] through detecting the position of palm based on the Leap Motion, and mapping the physical space and information space. As one typical application of the Leap Motion, a MIDI controller using the Leap Motion was reported in the literature [15] and it is also well known that many video games can be played with motion sensors such as Kinect. With the fast development of motion sensing technology, the Leap Motion can serve as an excellent alternative means of Kinect for desktop applications. After extensive testing, one may easily draw a conclusion that the motion sensing technology is more practical and more attractive than traditional way. As to the dynamic hand gesture recognition, in [16], an effective method which can recognize dynamic hand gesture is proposed by analyzing the information of motion trajectory captured by the Leap Motion.

1.2.4 SensAble Omni

The SensAble Omni Haptic Device is made by SensAble® haptic Technologies. This haptic device is of 6 DOFs, in which the first three DOFs contribute to position while the last three form a gimbal contributing to orientation. A stylus equiped with two buttons is also attached to the end effector. Note that the SensAble Omni has been very popularly used in the teleoperation research. The Omni device was utilized on