Chapter 1
Introduction

According to the World Robotics 2011 report [79], up to the end of 2014, more than 14 million service robots will populate the world. A *service robot* is a robot which operates partially of fully autonomously to provide services useful to the humans [10]. The group of service robots can be further divided into *professional service robots*, intended to perform service tasks at a professional level, and *personal robots*, suitable for education, assistance or entertainment tasks at home. Among these, it is of special interest the group of *assistive robots*, which main purpose is to help elderly and impaired people in their daily life.

It is well-known that the elderly population is considerably increasing in the industrialized countries, in percentage with the overall population. Figure 1.1 shows the eight countries with a higher estimation of elderly population in 2010 and 2050 [135]. It is expected that the percentage of people over 65 years old will almost duplicate in most of the industrialized countries by 2050. In the concrete case of Spain, estimations report that it will be the third country with more elderly people in 2050, only after Japan and Korea.

The elderly population constitute, together with impaired people, a group of the society that have to face with innumerable problems in their daily life. According to a report of the Spanish statistics institute [81], in the year 2008 a 23.19% of the

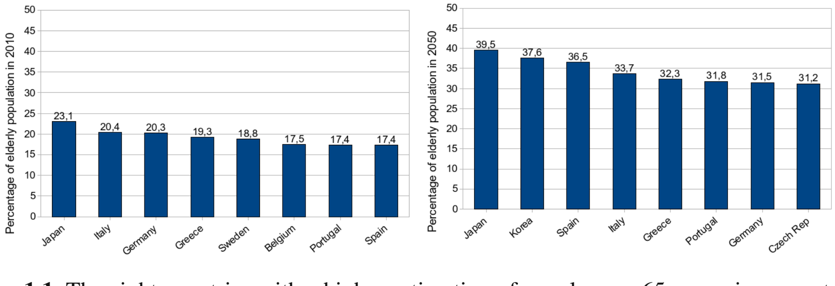

Fig. 1.1 The eight countries with a higher estimation of people over 65 years, in percentage to the overall population, in 2010 and 2050

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Spanish homes contained at least one disabled person (approximately 3.3 millions of the Spanish homes). In 608.000 of the cases the disabled person was living alone. The report also states that in approximately the 39.85% of the Spanish homes with disabled members, the impaired person is, in addition, more than 65 years old. The most common case of a home containing impaired people above 65 years is that composed of two persons, which represents a 40.48%, whereas in the 24% of the cases, the disabled and elderly person is living alone. The 74% of disabled people report difficulties to perform basic daily activities, such as personal hygiene, dressing, feeding, cooking, doing housework, moving around the home and performing simple tasks. Although this is the particular Spanish situation, these numbers seem to be in agreement with other industrialized countries.

Surprisingly, it is estimated that around the 26.6% of the impaired Spanish population (more than a million persons) does not receive any help for performing those tasks for which they have difficulties. This percentage highlights that current technical and personal assistance practices are insufficient. The high-costs of the healthcare sector, together with the lack of independence that assisted people experiment, lead to living conditions which are still unsatisfactory for most of the elderly and impaired population. The society is now facing the challenge of how to effectively take care of these persons, providing low-cost assistance and increased comfort. Assistive robots may represent a valid solution.

Several surveys have reported the convenience of assistive robots for the people with necessities [174, 65, 136]. An assistive robot able to perform everyday tasks would allow the people with mobility and other problems to live independently and autonomously. Among the functionality that users would demand from an assistive robot, the most highly rated are: do housework, prepare drinks and food, reach books and other objects from a shelf, plugging things, loading a video, watering plants and other gardening tasks, get items from the refrigerator, turn knobs, open/close doors and drawers, turning appliances on and off, and operating light switches.

Current robotics technology is still very distant from reaching all of these functionalities [87], which in most (or all) of the cases require advanced manipulation capabilities, offering advanced levels of versatility, autonomy and dependability. There are still no autonomous assistive robots with manipulation capabilities (from now, *assistive manipulators*) that have reached enough maturity for becoming commercially available. Only the Manus arm [42] is being commercialized as a manipulator that can be attached to a wheelchair and controlled by the user with a joystick or other input device. However, some start-up companies have ambitious plans to improve and commercialize their mobile assistive robotic prototypes, as, for example, the *Personal Robot* project [191] of Willow Garage, or ReadyBot [153]. In other cases, collaborations between big companies and universities aim at the same goal, as it is the case of the *Home Assistant Robot* [64], which is being built by researchers at Tokyo University in collaboration with Toyota. If we move into research groups, most of the research on assistive robot manipulation has been focused on wheel-chair manipulators [13, 3, 42], although interest on multipurpose mobile manipulation and humanoid robots is increasing considerably. One example is the Care-O-bot II assistance robot, which was introduced in [59], and included a manipulator that allowed to perform fetch and carry task, as an extension to Care-O-bot I [166] which did not include any manipulation capabilities. Reference [132] described a mobile manipulator for performing assistive tasks inspired in service dogs, which was able to open doors and drawers by grasping colored towels tied to the handles. The STAIR (STanford AI Robot) project [151] is aimed at building a mobile manipulator that can navigate through home and office environments, assisting users in their everyday actions. Finally, four outstanding examples of assistive humanoid robots are the Armar-III robot [6], HRP-2 [85], Twendy-one [185] and Justin [17].

The lack of commercial assistive manipulators is in contrast with the number of other service robots which have already succeeded in other areas, such as robot nurses [125], museum guidance robots [172], robots at hospitals [51], blind-guiding robots [94], tele-presence robots [156], or entertainment robots [155, 77]. Some of these machines are already being commercialized (or have plans to) by companies like Neobotix, WowWee, Anybots, I-Robot, etc. Surprisingly, none of the commercialized service robots include manipulation capabilities, and most of them even come without arms and hands. One possible reason is that robotic manipulation has still not reached the required levels of versatility, autonomy and dependability that other areas of robotics have achieved. Whereas current mobile robots are able to navigate around the environment in safety conditions, robotic manipulation seems to be still in its early stages, and a long way from the capabilities found in primates. Versatile, autonomous and dependable robotic manipulation techniques are required that open the doors to the development of useful assistive robots.

It is thought that, in a long perspective, the assistive robotics market will be a key area in robotics, and even the emergence of a new industry [56, 60]. An assistive robot with manipulation capabilities would not only have direct positive implications for the care of the elderly and impaired people, but also on other areas such as remote surveillance, tele-presence, space exploration, etc. Current commercial surveillance robots used by security companies do not include manipulation capabilities. This fact highly limits the mobility of the robot, which cannot open doors for accessing to new spaces. The inclusion of advanced manipulation functionalities into these robots would allow remote operators to access new spaces through doors and elevators, or to switch off the lights, for example. Similarly, an assistive robot at home could be used remotely by the owner in order to operate home appliances, close/open windows, check the availability of an item, etc., or by a user with mobility limitations in order to bring a drink from the fridge, grasp a book, and so on.

The purpose of this work is to advance towards more versatile, autonomous and dependable manipulation. More concretely, we support that a further integration of two aspects that have been normally considered independently, the grasp and the task, could imply a breakthrough in robotic manipulation. Classical studies of the human prehension capabilities report that the intended task represents a very important aspect for the selection of a suitable grasp or contact configuration in humans. Conversely, the contact configuration on a given object introduces limitations in the number of tasks that can be performed with it, and it is of utmost importance that

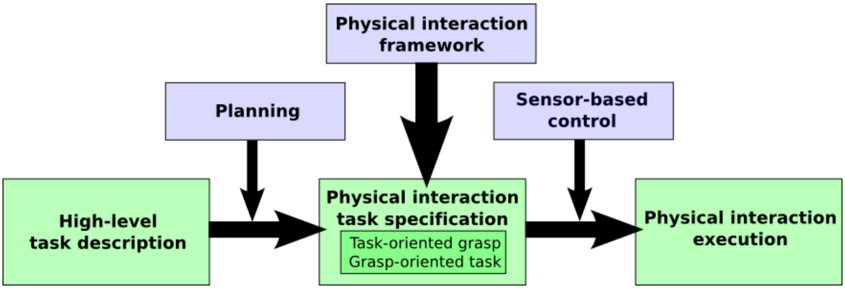

Fig. 1.2 A summary of the contributions of this book

the contact state remains suitable during the overall execution of the task. This interplay has been rarely considered in the robotics community. Research on grasp planning normally focuses on the particular task of pick and place. However, the kind of tasks that humans perform in their daily life goes far beyond pick and place tasks. Similarly, research on task planning and constrained motion control usually assumes that an appropriate contact configuration has been previously achieved and that it remains suitable during the execution. There is a lack of collaboration between grasp-based and task-based approaches.

In our opinion, this lack of grasp-task integration introduces important limits in the achievement of the desired properties of versatility, autonomy and dependability in robotic manipulation. Firstly, as the task requirements are not considered in the selection of the grasp, robot grasping capabilities are typically limited to general pick and place actions. Secondly, the lack of grasp planning inside task execution approaches normally leads to ad-hoc solutions which are only valid for one particular system and task. And, finally, the absence of grasp control processes during the task execution prevents the detection of changes in the contact configuration and its corresponding correction.

Therefore, we advocate for the introduction of task-related aspects into the classical knowledge-based grasp concept, leading to *task-oriented grasps*. In a similar manner, grasp-related issues are also considered during the execution of a task, leading to *grasp-oriented tasks*. Both task-oriented grasps and grasp-oriented tasks compose a unified representation which we call *physical interaction*. This new concept suppresses the classical boundaries between the grasp and the task, and introduces the new problems of physical interaction *specification*, *planning* and *execution*.

In this monograph, we propose several contributions in these lines, as depicted in Figure 1.2. First, a *theoretical framework* for the integrated specification of physical interaction tasks is defined. The framework is built on top of two well-established approaches to grasp planning and task specification: the knowledge-based approach, and the Task Frame Formalism. The link between the grasp and the task is established by means of the relationships between several coordinate systems called the *physical interaction frames*. The proposed framework allows for an integrated specification of a grasp and its subsequent task, and supports a great variety of actions, not only involving direct hand-object manipulation, but also the use of tools or manipulation with two hands. Next, the problem of *autonomous planning* of physical interaction tasks is addressed. From a high-level task description in terms of *object actions*, the planner selects an appropriate *task-oriented hand posture* and builds the physical interaction task specification using the previous framework. We then focus on the *dependable execution* of these physical interaction tasks, which is probably the most important part of this work. A *sensor-based approach* is adopted, and three different types of sensor feedback which provide rich information during human manipulation are considered: force, vision and tactile feedback. Several strategies for processing and combining the information coming from these sensors in different manipulation situations are proposed, including reliable force-based methods, a novel *vision-force control* approach, and a *hybrid vision-tactile-force controller*. Finally, all the contributions of this book are validated with experiments on real robots, including two different mobile manipulators and a humanoid robot. This work also presents the first steps towards a useful assistive manipulator: the *UJI Service Robot*. The number of different robots where these methods have been implemented, and the variety of tasks that have been considered, show the versatility of our approach, and its suitability for the autonomous and dependable execution of tasks under modelling errors and geometric uncertainties.

This book is organized as follows. Chapter 2 describes the state of the art in grasp and task control and identifies a lack of general approaches that consider the *grasp* and the *task* as related problems. The concept of *physical interaction* is then introduced as a more general approach including both aspects, and the methodology for developing such concept is explained. Chapter 3 establishes a conceptual framework that allows to specify physical interaction tasks with sensor-based control purposes, in terms of the *physical interaction frames*. Chapter 4 describes a *physical interaction planner* based on the previous framework and the new concepts of *task-oriented hand preshapes*, *object actions* and *object tasks*. Chapters 5, 6 and 7 explore different sensor processing methods and control strategies for the robust execution of physical interaction tasks, including, respectively, force-only, vision-force and vision-tactile-force control, paying special attention to its applicability in real situations. Chapter 8 focuses on the application of the framework, planner and control methods into a service robot prototype, and describes future challenges to be addressed as natural extensions to this work. Finally, the main contributions of this book, together with the conclusions and future work, are remarked in chapter 9.