SORBONNE UNIVERSITÉ

Ecole doctorale SMAER
Sciences Mécaniques, Acoustique, Electronique, Robotique

Thesis subject 2018

Laboratory: ISIR (Institute for Intelligent Systems and Robotics) UMR 7222

University: Sorbonne Université

Title of the thesis: Bi-manual human robot manipulation

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Collaborations within the thesis: Already existing collaborations will be expanded to contribute to the thesis development and help prepare a proposal for an international collaborative project on this research theme (Faculdade de Ciências e Tecnologia da Universidade de Coimbra, Portugal - German Research Center for Artificial Intelligence GmbH, Kaiserslautern, Germany – Institut Pascal, IFMA, Clermont-Ferrand - Université de Technologie de Compiègne)

This subject can be published on the doctoral school's web site: YES

Thesis's summary (abstract):

Robots are becoming more and more present in our daily lives, but they continue to be used in very limited industrial workspaces where no collaboration with human operators is permitted due to safety reasons and the lack of flexibility of these systems. The research of this thesis will cover this gap in current industrial setups by developing a co-working system where a human operator can collaborate with a robot (robotic arm and anthropomorphic hand) in performing manipulation tasks together. This system will have two main objectives: avoiding the musculoskeletal injuries suffered by human workers due to the repetition of uncomfortable gestures and increasing the productivity of the production line by parallelizing processes that can be done by the human and the robot if they share their workspaces. This interaction between the human and the robot should not only be safe and efficient but also natural so that the human can understand the robot's behaviour and can be extended to assistance applications. In order to implement such a human-robot interaction system, first of all, manipulation tasks performed by human will be observed in order to parametrize them in terms of efficiency (execution time), ergonomics (comfortable gestures) and interaction (naturalness). Secondly, a model of human manipulation tasks will be inferred in order to substitute one of the human by a robot, which will plan its movements so that they are efficient, comfortable and natural for the human operator. The control system of the robot will combine information from several sensors (vision, force and tactile) to know the state of the environment and adapt the manipulation tasks accordingly. This system will be initially applied to hand-over tasks and then extended to more complicated co-manipulation

tasks with complex objects. The solutions developed will be implemented on the experimental platform of the European project HANDLE.

Subject

Robots have become part of the society in assisting workspaces (Hirukawa 2007) medical environments (Hoekstra et al, 2009) and manufacturing but also as working devices in homes (e.g. lawnmower, vacuum). In a human workspace, handling loads with another human is a common practice to increase productivity and efficiently share the workload. Shared labour between humans and robots may change the collaboration and interaction possibilities during the work process. This project will tackle with the human-robot collaboration in object manipulation.

State-of-the-art

The human-robot interaction is a very sophisticated challenge which has been approached in detail for robot-human handovers (Shibata 1995). The physical interaction between humans is a natural process, involving passing objects between people. The tactile sense (Johansson and Westling,1984) and the characterization of haptic interaction in human-human handovers is well known (Chan et al., 2012). However, in robot-human handovers the settings change drastically and the robot has to be adapted to achieve the handover task obeying to safety regulations (Wesley et al. 2013) without permanent communication or readjustments of the robot. In co-shared workplaces with continuous human-robot interaction, robotic assistance and interactions have become relevant (Bischoff & Guhl, 2010). Humans in contrast to robots have the ability to adapt to specific task requirements while robots have the benefit of spatial precision, repeatability and the potential of applying specific forces. The general handover task is often described by a passer/receiver as initiating and leading the task (Huber et al. 2008; Mason & MacKenzie 2005). In order to pass an object, either the robot learns the trajectory from humans (Yamane et al. 2013) or plan it reactively according to the constraints and changes of the environment (Lawitzky et al. 2012). Also information about the object itself (e.g. physical and mechanical properties) is necessary (Wesley et al. 2013). Extreme positions during the handover are usually avoided and the robots workspace is usually limited to avoid interferences. To improve movement fluency, an overlap in the movements of the involved participants occurs (Prada, 2013) and natural reaching gestures have to been performed (Edsinger & Kemp, 2007) in order to correctly identify the moments of object transferring.

To achieve robot-human handovers, the robot has to track and localize (Corrales et al. 2010; Corrales et al. 2011) the human to guarantee its safety (Corrales et al. 2013) and avoid collisions (Haddadin, 2009). The robot optimizes objective cost functions that take safety (Mainprice & Berenson, 2013) and comfort parameters into account (Aleotti et al. 2012) but also avoid robot-human misunderstandings and possible injuries (Dehais et al. 2011) and maximize visibility of the object (Sisbot & Alami 2012). When the robot hands an object as a hammer to a human, the hammer has to be delivered in a comfortable way by orienting the handle towards the human torso (Aloetti et al. 2012). This becomes even more important when the object itself may cause injuries as e.g. a knife (Wesley et al. 2013). Especially the interaction between robots and human operators during handover tasks is a key issue in manufacturing to reduce costs, increase efficiency and improve the flexibility of the human-robot workplace. Based on the above-mentioned facts the biomechanical and physiological studies of the robot-human interaction is of utterly importance to improve and judge the efficiency of co-shared workplaces in manufacturing. Biomechanical models are necessary to capture the mechanical dynamics of the musculoskeletal system (Vignais & Marin, 2011), during the interaction with robots to evaluate the safety and arduousness of the co-working task (Vignais et al, 2013).

Improving human-robot object exchange is possible by online force classification and allows actors with no experience with robots to deal with human-robot handover (He & Sidobre, 2015). This in object transfer is also improved by means of visual servoing (Wang et al., 2015). A new description of physical human-robot interaction tasks involving two-arm coordination has been made considering the human-robot pair as a global system (Adorno et al., 2014) potentially leading to interaction improvement between assistant robots and impaired individuals. Coordination strategies in handover tasks are now very well studied where robots adapt to their human partner's demands (Huang et al., 2015) or learn from human feedback (Kupcsik et al., 2016). Another solution to safe human-robot collaboration is to design the workspace, e.g. for assembly stations (Michalos et al., 2015). With robots always more complex and involved in humans' life and work, it is worth considering psychological/social impact of robot's mistakes on our collaboration as Salem et al. (2015) investigated it in term of trustworthiness. As robots' presence and interaction with humans increases, navigation in dense human crowds based on human cooperation (in avoiding robots) is a field that must be critically considered (Trautman et al., 2015).

Research facility

The HANDLE platform composed of a pneumatic robotic arm with 4 degrees of freedom (dof), an anthropomorphic Shadow robotic hand with 20 dof equipped with 6D force sensors at fingertips, tactile sensors on fingers' phalanxes and palm, and a Kinect camera.

Research task

The main objective of the research developed in this project will be establishing the basis needed for developing a co-working system where humans and robots can collaborate in order to perform manipulation tasks in a natural, comfortable and optimal way. These collaboration tasks could be applied in manufacturing environments not only to reduce the possible muscle-skeletal damages that current workers suffer due to repetition of uncomfortable manipulation tasks but also to improve the productivity of the system when the robot becomes an assistant for the human so that more tasks can be done in a parallel way. Nevertheless, this collaborative system could also be applied in assistance applications where the robot helps elderly or disabled people for performing manipulation tasks. Compared to existing solutions, we aim to develop a closer collaboration than usual hand-overs (which are more a coordination problem than a cooperation one). Cooperation tasks will be explored (such as assembly tasks) where the robot and the human are in contact by means of an intermediate object during the whole task progress.

In order to develop this final goal, the research will be divided into a few steps:

1. Modelling and parametrization of human manipulation tasks: First of all, we will model the way humans perform collaborative manipulation tasks in order to replicate this with the robot. We will record a set of manipulation tasks performed by two people using a motion capture system. Then, we will extract automatically from the recorded data two types of information: i) parameters which define the ergonomics of the task according to a muscle-skeletal model of the human and ii) parameters which define the actions required to perform the task (types of grasps, transitions

between these grasps, trajectories of the arms, relative pose of the object, etc.). Finally, each execution of the task will be labelled with weights which represent the cost of performing this task in terms of efficiency (time to complete the task) and ergonomics (comfort of the human while doing the task). Therefore, we will generate a database that will not only contain different ways to perform the same manipulation task but also its associated costs. In addition, this database will store the cues that are required to switch from one action to another during the interaction for example, changing the gaze direction from the object to the human in order to show that the object is going to be transferred in hand-over action).

2. Online robot planning for natural and efficient human-robot collaboration: After the way for executing a manipulation task has been analysed and learned from two humans in the previous step, one of this human will be substituted by an assistant robot. A novel planner will use the information recorded in the previous database in order to control the movements of the robot in such a way that the robot behaves in an efficient and comfortable manner. In fact, the planner will choose the sequence of actions which corresponds to the best balance between finishing the task efficiently (this means reducing the final execution time by increasing the number of actions which can be performed in parallel by the robot and the human) and performing it in a comfortable way for the human (this means reducing the injuries for the human due to long repetitions of the same task). To do this, the planner will use the costs stored in the database and choose the action sequence which minimizes both costs according to the current state of the environment: pose of the human including his upper limbs, pose of the robotic system – hand + arm – and pose of the object to be manipulated. Obviously, the robotic system will not replay the exact movements stored in the database but will use them only as template that is adapted to the real requirements of the current task: the grasp will be adapted to the size of the object, the trajectory of the arm will be changed in order to avoid collisions, the final desired position of the object will depend on the human hand's pose, etc. This adaptation will be executed in real-time according to sensor data (vision, force and tactile sensors). The task cost (combination of efficiency and ergonomics) will be permanently updated, meaning that the next actions of the task may change if the current execution is no more the optimal one due to a change in the environment. Therefore, the planner will be reactive to changes that normally happen in cluttered environments with humans. In addition, the system will detect the transition conditions (changes of gaze direction, changes of hands/arms positions, etc) identifying the changes between actions in order to stop the execution of the current action and start the following one in a natural and intuitive way for the human. Therefore, a real natural and unobtrusive collaboration will be achieved.

This co-working system will initially be developed for handing-over tasks of simple objects. But later, it will be extended to more sophisticated tasks which require real co-manipulation of the same object by the human and the robot and to objects that have specific parts or configurations which are required to accomplish the task (such as handles to hold cups or keeping upwards opened bottles in order to avoid accidental pouring).

Other interesting subjects would be covered such as the manipulation of small size objects, moving from coordination tasks (handovers) to more collaboration tasks (assembly tasks), quantifying how much a human can trust his/her co-working robot.

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