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Integrated sensors system for human safety during cooperating with industrial robots for handing-over and assembling tasks

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Abstract

Human safety is the main concern which prevents performing some tasks requiring physical interaction between human and robot. Therefore, the safety concept was previously based on eliminating contact between human and robots. This paper will propose a robot system which integrates different types of sensors to ensure human safety during the physical human robot interaction. The implemented sensors are vision, force and sensitive skin. Using vision system, the robot will be able to detect and recognize human face, loadfree human hand and any object carried by human hand (active hand). Furthermore, it will help the robot to define in which directions the force should be applied and what are the dangerous directions for human safety. The force sensor will help the robot to react to the motion of the human hand during the handing-over or assembling task. The sensitive skin will prevent any collision between the human and the robot arm. The proposed system is supported with a voice system for informing human about the actual status of the system.

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1. Introduction

Physical interaction between human and robot consists usually of two main parts: the human hand and the robot hand. However, in most service robots applications this interaction will not be performed directly between human hand and robot hand, but a target object will serve as a connection bridge between human hand and robot hand. The target object could be a transferred object between the human hand and the robot hand or an object which needs to be assembled, operated etc.

For better understanding of the behavior of human and robot before starting the physical interaction phase, the handing-over task will be taken as an proposed example. In every handing-over task there are two parties: the giver and receiver, and an object which will be transferred. By handing over an object from human hand to the robot, the human will be giver and the robot will be receiver. Otherwise, the robot will be giver and the human will be receiver. This work will divide giver/receiver (two parties; human and robot) into three types depending on their behavior during the handing-over:

- Positive giver (receiver): In this case, the giver will play a positive role during handing-over of the objects. In other words, the giver will move toward the receiver and track it to achieve smooth handing-over task.
- Neutral giver (receiver): In this case, this party will try to fix its hand in a stable pose, and the receiver should move toward it to achieve the handing-over task.
- Negative giver (receiver): Here, this party will play a negative role; party is e.g. elderly or blind or he/she is doing something else at the same time. In this case, the receiver should expect some random motions from giver during the task and react accordingly to them.

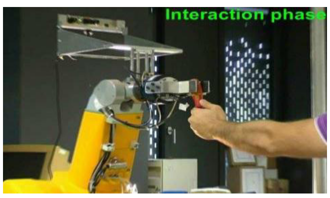

Fig. 1 Human-robot interaction

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Hence, if both parties the receiver and the giver behave as negative or neutral parties, the physical interaction will not be accomplished. At least one of both parties should perform the task positively by tracking the other party, defining the contact point, searching for contact and also tracking during the interaction phase in order to achieve a smooth handing over task. All the possible cases are represented in the table I.

TABLE I BEHAVIORS OF HUMAN/ROBOT

	Human	Robot	Physical human robot interaction
1	Negative	Negative	Unsuccessfully performed
2	Negative	Neutral	Unsuccessfully performed
3	Negative	Positive	Could be successfully performed, if robot is faster than human
4	Neutral	Negative	Unsuccessfully performed
5	Neutral	Neutral	Unsuccessfully performed
**6	Neutral	Positive	Successfully performed
7	Positive	Negative	Could be successfully performed, if human is faster than robot
*8	Positive	Neutral	Successfully performed
**9	Positive	Positive	Successfully performed (the optimal case)

* The common approach in the previous works.
** The proposed approach.

In general, the common used approach in the previous works is the case 8, e.g. [1], [2], [3] and [4], where the tasks are performed exclusively by the human. This means that the robot will bring the robot hand into a specified position and orientation and then it will wait until the human places the object between the fingers of the gripper. When the robot detects that an object has been placed in its hand, it attempts to grasp the object, the same case has been applied previously for handing-over object from robot to human or during the performance of assembling task. In fact, this scenario will not be fit to assist blind, disabled or elderly people or even to support workers concentrating on their work. The main reason which leads the previous works to choose this approach is the factor of human safety. The robot is not allowed to move (stay stable and behaves as neutral party) when the human is moving toward it.

In this work, we will assume that the human is the weakest party of human-robot team (blind, disabled or concentrated on his own work), i.e. the transfer or the physical interaction task will be exclusively established and controlled by the robot. Therefore, we should propose an integrated sensors system which ensures the safety of the human. As a consequence, if the robot was able to perform the task when the human behaves as negative or neutral party, so for sure it will be able to perform the task efficiently when the human is positive party.

This paper will not only present the vision and force information as control signal, but it will illustrate; how the robot system can benefit from these signals in order to insure the safety of the human, how to integrate these information together with skin sensor feedback, how the robot can use all the available information which could be provided by vision sensor not only for the target object but also for the whole scene. Using vision system, the robot will be able to detect human face, to recognize loadfree human hand or any object carried by human hand (active hand). Furthermore, it will help the robot to define the optimal combination of vision, force and skin sensor (in which directions the force should be applied and what the dangerous directions are) in order to guarantee the human safety, to ensure the fulfillment of grasping task and to react to the motion of human hand during the interaction phase. Hence, the robot will play the main role as a positive party to perform the task. This scenario could be useful in various applications, e.g. with robot assistants for blind, disabled or elderly people helping them in fetching, carrying things or transporting objects. In other applications the robots serve as members of human-robot team as physical support to humans for such applications as space exploration, construction, assembly etc.

The proposed system will be shortly presented in the next section. In section 3, the procedures for safety issues will be illustrated. Section 4 presents briefly the control algorithms. The last section contains the conclusion, future work and the benefits of improving the physical interaction between human and robot.

2. Proposed System

This section describes the proposed system representing the feasibility of integrating vision, force and skin sensor feedbacks in order to insure the human safety during the physical interaction between human and robot.

Many algorithms have been proposed to avoid the collision for the whole arm of the industrial robots using skin sensor. However, many of them have required a large number of sensors, e.g. in [5] it is presented a prototype of sensing skin for a robot arm. Rings of Sensors are around the robot link, each ring consisting of several infrared range sensors, which can detect objects in a distance range between 4 and 30 cm. In [6] it has been developed a sensitive skin consisting of hundreds of active infra-red proximity sensors that cover the whole arm body. Another work [7] has presented a cost-effective invisible sensitive skin that can cover a large area without utilizing a large number of sensors and it is built inside the robot arm. Only 5 contactless capacitive sensors and specially designed antennas are used to cover the whole arm of a 6-DOF industrial robot. The sensors, antennas and wires are all built inside the covers the robot arm and the sensing distance of each sensor is 10cm. In fact, this approach is very fit to be combined with the proposed system and its information could be easily integrated with the vision and force feedback.

The overall setup of the proposed system consists of an industrial robot provided with vision and force sensors. In our experiment, the implemented system is a Stäubli RX90 robot with a JR3 multi-axis force/torque sensor together with the eye-in-hand camera system. The end-effector is installed on the collision protection device. The end-effector is the two-fingers gripper which hold the object. it has digital input (0 = open, 1 = closed). JR3 (120M50A) is a six component force/torque sensor and its effective measurement range is ± 100 N for forces and ± 10 N.m for torques . The vision