FP6 - 045359

# PHRIENDS

## Physical Human-Robot Interaction: DepENDability and Safety

Specific Targeted Research or Innovation Project
Sixth Framework Programme Priority 2
Cognitive Systems

## *Deliverable D3.3*

## *Reflex Robot Reaction to Collisions*

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| **Dissemination Level** | | |
| **PU** | Public | |
| **PP** | Restricted to other programme participants (including the Commission Services | |
| **RE** | Restricted to a group specified by the consortium (including the Commission Services) | **X** |
| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |

## Executive Summary

This deliverable of work package WP3 describes a set of possible reaction strategies that can be activated for the robot in response to a detected collision. In deliverable D3.1, novel physically-based methods for detecting and isolating collisions using only proprioceptive sensors were presented. Specifically, the method based on variations of the generalized momentum produces a so-called residual vector during the short impact phase, which is a filtered estimate of the joint torques produced by collision. During the post-impact phase, directional information about collision which is embedded in the residual can be used for defining a reactive motion of the robot. As a result, the robot arm will rapidly and smoothly bounce away from the collision area. While other more sophisticated reaction strategies are possible, this ”reflex” motion of the robot addresses safety as the highest priority in this situation. Different ways to realize such reaction strategies are presented for the case of rigid manipulators, and then extended to the case of robots with joint elasticity. Experimental results obtained on the DLR LWR-III robot are reported to illustrate and compare the performance of the complete collision detection/reaction methods.

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# 1 Introduction

Undesired collisions between a robot and a human that share the same workspace occur mostly because of an unpredicted, typically fast motion of the human. This type of uncertain and potentially dangerous human-robot physical interaction can be divided in three timing phases: pre-impact, impact, and post-impact.

During the pre-impact phase, the primary goal is to plan safe and legible trajectories for the robot and anticipate/prevent collisions, typically by making use of external sensors.

When a collision cannot be anymore avoided (impact phase), it is important to recognize this event as soon as possible. In this phase, we have identified two monitoring situations: collision detection recognizes just the occurrence of a collision; collision isolation characterizes further a collision by providing information also on the robot link(s) where impact may have occurred.

Achievement of collision isolation is very important for setting up a suitable robot reaction, which is the core of the post-impact phase. It is rather evident that, without any information on where the collision has occurred, it will be difficult to find a direction along which the robot can be safely moved away from the contact with a human user in response to a detected collision. This explains also why in industrial robots having the collision detection (but not the isolation) feature, the only strategy currently implemented in the post-impact phase is to stop the robot.

In this document, we focus instead on more active collision reaction strategies. Once activated either by a collision detection or isolation method, these typically involve a switching from the control law that was being used in the pre-impact phase. We will present a set of useful reaction control commands that can be used for responding safely to a collision. All these strategies are based on the use of the residual vector, generated during collision isolation in the short impact phase. The residual is a filtered estimate of the joint torques produced by the collision (see deliverable D3.1 for the details).

One interesting feature of the combined detection/reaction approach is that it allows handling successive collisions over time. In fact, the method for detection and isolation of collisions remains active also after a first collision has occurred, being independent from the specific control command applied (i.e., during normal task execution or for collision recovery). The overall approach proposed in PHRIENDS to collision detection and reaction is shown in Fig. 1.

After recalling the background on collision isolation, reaction strategies will be presented first for the case of rigid manipulators and then extended to robots with joint elasticity. Experimental results are reported for the DLR LWR-III robot colliding with different obstacles, including dummies and humans, and reacting with different strategies. This lightweight robot is equipped with harmonic drives, showing non-negligible joint elasticity. Moreover, it is equipped with torque sensors at all the seven joints. While this is not strictly necessary for the applicability of the combined detection/reaction methods, it conveniently allows treating the problem similarly to the case of fully rigid robots $B = 1$.

$$a_j \frac{a_k}{b^2} = A^{e_j^2}$$

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + g(q) = \tau \tag{1}$$

Citing equation as eq. (1).

# 2 Background on collision isolation

## 2.1 Hello

Example of citation [1]

## References

[1] S. Thrun, W. Burgard, and D. Fox, *Probabilistic robotics*, MIT Press, Cambridge, MA, 2005.