Human-centered robotics – Biomechanics & Safety Laboratory of the Robotics and Mechatronics Center

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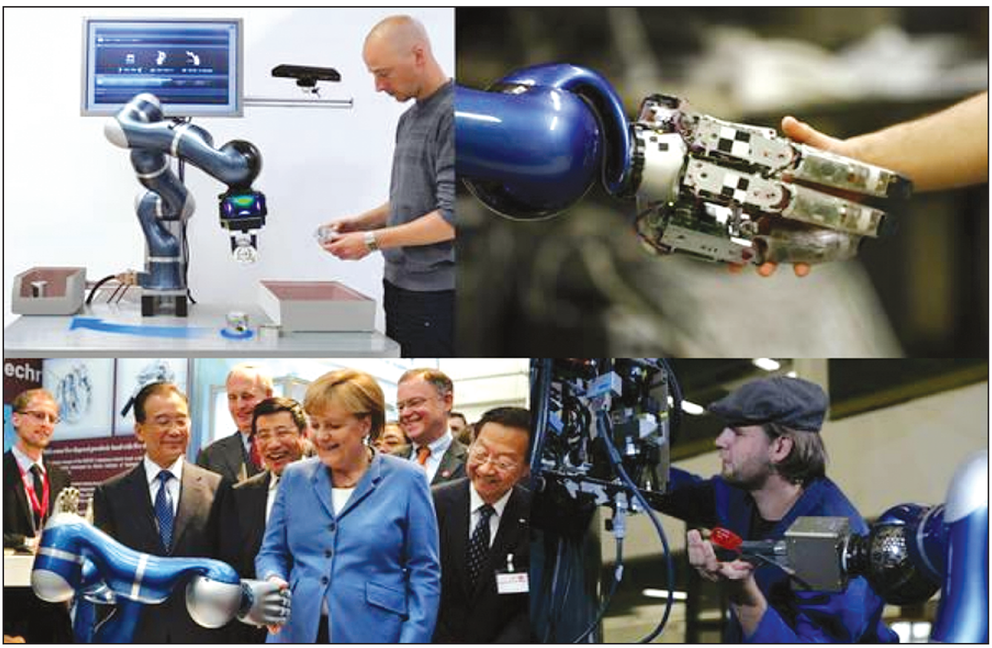
The Institute of Robotics and Mechatronics (RM) of the German Aerospace Center (DLR) is part of the Robotics and Mechatronics Center (RMC) and has been a research facility on international level for the past three decades. RM is located on the DLR-campus in Oberpfaffenhofen, Germany in Munich's southwest and employs 150 scientists. Its Biomechanics & Safety Laboratory belongs to the Human-Centered Robotics group. The laboratory was established in 2008 and by now regularly employs two post-doc researchers (engineer and physician), three graduates and one technician. Furthermore, the laboratory regularly accepts students (engineering, medicine) to prepare their final thesis in the field of *biomechanics* and *safety* with particular focus on *robotics, electrical engineering* or *computer science.* There is a strong drive in multidis-



Physical Human-Robot-Interaction (pHRI) as an enabler for robotics in society ciplinary research between engineering and medical sciences, particularly in the field of physical Human-Robot-Interaction (HRI).

The work is part of several internal DLR projects and various European projects such as PHRIENDS, VIACTORS, and SAPHARI and industrial collaborations with KUKA Roboter GmbH, KUKA Labs, and Daimler AG. Furthermore, several collaborations with international partners such as Stanford University, Willow Garage, Inc., Johns Hopkins University, Korea University, and Technical University of Munich have been established.

Crash tests: chest collision, neck extension, drop test device, sharp contacts with porcine leg (from top left to bottom right)

Research Topics

The research goal of the Biomechanics & Safety Laboratory is to enable robots for direct physical interaction and cooperation with humans and transferring the resulting technology to industry and real world applications. For this, new generations of safe robots were developed at RMC. These devices are sought to act as human assistants in a variety of application domains:

- industrial assembly and manufacturing,
- medicine, or
- house-hold helpers in everyone's home.

In such applications it has to be ensured that the robot will under no circumstances injure human due to malfunction, even in case of user errors. For this, a systematic approach for human injury analysis and prevention had to be developed that bridges the gap between robotics and biomechanics. For quantifying what safe behavior really means, the definition of injury, as well as understanding its general dynamics are essential. The problem is approached from a medical injury analysis and biomechanical point of view in order to formulate the relation between robot mass, velocity, impact geometry and resulting injury in medical terms. The results are classified according to the AO-classification or the appropriate severity indices, as for instance Head Injury Criterion (HIC), Neck Injury Criterion (NIC) or Abbreviated Injury Scale (AIS). Collisions are evaluated by macro- and microscopic examination, medical imaging (MRI, sonography) and biomechanical parameters. Besides injury classifications, the utilization of robotic systems in collision tests yields factors that can be directly measured such as impact force, velocity, stress and penetration depth. The aim of these efforts is to study and classify all relevant injuries that may appear in accidental robot-human collisions. Furthermore, a large experimental database for understanding and evaluating these potential injuries is generated. In order to investigate the inherent risk emanating from robotic systems, the devices are tested exhaustively with mechanical devices and crash-test dummies, drop tests on animal specimens, voluntary human-robot collision experiments and computer simulations. The tests are primarily performed in our institute, but also externally as for instance the standardized crash-test facilities at the German Automobile Club (ADAC) or the university clinic *Klinikum Rechts der Isar* of the Technical University Munich (TUM). Several industrial robots ranging from less than 10 kg up to 2500 kg were evaluated up to now. After the relevant information about the mechanisms of such injury was extracted, the next step was to design appropriate countermeasures by means of collisions detection and appropriate reaction. These are developed in such a way that they are also able to resemble a human's behavior during such collisions. It was shown that based on its force and torque sensing capabilities, the robot is able to reduce or even entirely prevent injury even in case of entirely unforeseen collisions.

Standards

From the standardization side, there has been considerable effort in reflecting complex interaction research into existing industrial robot standards and define close human-robot interaction for service robotics, which is still significantly evolving. The results of the laboratory also yielded fundamental data for the newly developed *ISO-standardization* guidelines, specifically ISO-10128-1,-2 (Standard for Industrial Robotics), 13482 (Standard for Personal Care [Service] Robots) and the associated technical specification TS15066.

Future

It seems that we are finally getting to the stage of enabling co-existence and interaction not only in research lab environments and in terms of proof-of-concept installations in industry, but fundamentally changing the role of robotics for humans' everyday life. However, this is a major effort and several questions and requirements regarding safety remain open and unsolved yet. In this sense, the institute intends to bring together researchers, standardization experts, and industrialists, who are all together responsible for ensuring that robots can finally come off the research labs into all aspects of everyday life.

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