Safe Human-Robot Collaboration

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Safe Human–Robot Collaboration:
From Bio-mechanical Safety Limits to Real-Time, Personalized Safety Intelligence

Human–robot collaboration (HRC) is expanding across industrial, service, and emerging humanoid domains, creating operating environments where humans and robots frequently share physical space. Ensuring safety in such settings requires an integrated understanding of human biomechanics, robot dynamics, and collision physics. This lecture presents a framework that moves beyond empirical threshold-based rules toward precise, personalized, and posture-aware collision safety.

Early experimental studies established pain onset, injury tolerance, and characteristic force–pressure relationships for human–robot contact. Building on this foundation, our group at Kyung Hee University has performed extensive pain-tolerance tests, animal-based injury studies, and robot–dummy measurements using pressure–force devices. These results consistently show that collision safety depends on posture, contact direction, velocity, and the inertial interaction between human and robot.

To address these factors, we developed the KHU Collision Model—a skin-layered nonlinear dynamic formulation that integrates effective mass, contact geometry, and tissue mechanics. The model has been rigorously validated through FEM simulations, Hybrid-III dummy collisions, and robot–human contact tests, and has been deployed in real collaborative environments such as food-service and school kitchen robots.

A major contribution of this lecture is an upgraded representation of the human body within the collision model. While SMPL provides a detailed kinematic description of human shape and posture, we extend it to a full articulated dynamic model with segmental mass and inertia, enabling accurate computation of direction-dependent human effective mass. Simulations show that effective mass can vary more than twofold with posture, allowing collision risk to be estimated far more precisely and enabling personalized safe-motion limits.

By combining posture-dependent human inertia with robot effective mass, we establish a unified collision model suitable for real-time risk prediction and safe control, including applications in velocity modulation and learning-based trajectory generation. Because the proposed human model is structurally compatible with human-shaped robots, it also provides a natural foundation for future humanoid collision modeling.

The lecture concludes with the vision of Safety Intelligence—robots that understand human posture and dynamics, anticipate collision risk, and proactively adapt their motion—laying the groundwork for the next generation of safe and productive human–robot collaboration.