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Real-time 3D Collision Avoidance Method for Safe Human and Robot Coexistence

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***Abstract* - A novel solution to the three-dimensional dynamic human-robot collision problem is presented. Sphere-based geometric models are used for the human and robot due to the efficiency of the distance computation. The collision avoidance algorithm searches for collision-free paths by moving the end-effector along a set of pre-defined search directions. An optimization method is employed to select the search direction that balances between the robot approaching its goal location, and maximizing the distances between the human and robot models. The optimization incorporates predictions of the motions of the robot and human to reduce the negative effects of a non-instantaneous robot time response. The robot prediction is based on a transfer function model of its experimental time response at the joint level. The human prediction is performed at the sphere level using the weighted mean of past velocities. Predicting at the sphere level eliminates the difficulty introduced by the limbs moving in different directions. After describing the collision avoidance algorithm, a human walking towards a moving Puma robot arm is simulated. Captured motion data is used to make the human motion realistic. Monte Carlo simulations using 1000 random human walking paths passing through the robot workspace are used to evaluate the algorithm. The algorithm prevented all collisions due to the robot. The algorithm is deterministic and efficient enough to be used in real-time. On a 1.8GHz Pentium IV PC, a 40 Hz sampling rate was achieved.**

Index Terms - manipulator motion-planning, intelligent robots, geometric modeling, manipulators, safety.

I. INTRODUCTION

In manufacturing applications, robotic manipulators are isolated from humans for safety reasons using physical barriers or sensor curtains. If these robots were able to avoid humans the safe environment could be maintained without the need for a separate robot work area, and expensive factory floor space could be saved. In the cases when the robot must be near to humans, such as with mobile robots, the speed is kept slow to prevent harmful collisions from taking place. If the robot was capable of avoiding human-robot collisions it could be operated at higher speeds and factory productivity would improve. The ability to safely coexist with humans is even more important for service and personal robots.

The safety aspect of human-friendly robot design has been an active area of recent research. Some researchers have focused on approaches for minimizing the danger of human-robot contact, *e.g.* backdrivable joints and gravity compensation [1]; safer mechanical design [2]; improved actuation/controller design [3]; and a combination of high energy motors, carbon fibre links and impedance control [4]. Our interests are in applications where human-robot contact should be avoided, and in solving the associated real-time three-dimensional (3D) collision avoidance problem.

Human-robot collision avoidance is a challenging problem since, from a motion planning point of view, a human is a dynamic, multi-link, 3D obstacle whose motion is difficult to predict. In [5] a mobile robotic platform is modeled by enclosing it with a small number of large spheres. The initial planned path for the platform is modified in real-time for a moving obstacle using a novel elastic strip technique. A sophisticated approach based on a hierarchy of bounding spheres is used to model both the manipulator and the human in [6] for the purpose of collision detection. They report worst-case collision detection times of 40ms for a simulation of two Puma robot arms and a walking human. They did not present a collision avoidance method. Ref. [7] describes an optimization-based method for human-robot safety. They present simulation results for a manipulator approaching a stationary human. A high-speed machine vision-based approach to the human-robot collision detection problem is presented in [8]. Their system sends an emergency-stop command to the robot when the human gets too close. A planning method for safe interaction between human arms and robot manipulators was presented in [9]. They first construct a collision-free roadmap in C-space offline. This roadmap is updated online to handle the human's moving arms. They simulated two manipulators working in close proximity to two randomly moving human arms. On a 2.8GHz Pentium IV PC the worst-case time for updating the roadmap was 453ms.

In this paper we present a novel solution to the human-robot collision avoidance problem. Our approach is described in section II. Simulation results based on a realistic dynamic model for the robot, and on empirical human motion data, are presented in section III. Conclusions are given in section IV.

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