

# Superquadric Obstacle Modeling and a Danger Evaluation Method with Application in Safe Planning for Human-Safe Industrial Robots\*

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This paper concerns with human body modeling and danger evaluations to develop a path planning algorithm that addresses the issue of safe human-robot interactions (HRI) within industrial automation.

## 1 Motivations and Objectives

For many decades, industrial robots have greatly served mankind by reducing human fatigue, increasing force capabilities, and improving the quality of the production. In recent years however, the robotic industry has envisaged higher productivity in addition to other social and ethical benefits in the integration of man and machine within the industrial environments. The new approach is rationalized by the global knowledge, experience, flexibility of task executions, and intelligence that a human can bring into the precision, strength, and agility of the robotic automation [1]. This is where the majority of the protection strategies currently in place within the industrial environments are based on isolating the robots from their surroundings [2]. These strategies are at odds with the idea of bringing robots closer to humans and are often found inadequate for the new interactive environments. In fact, it has been shown that a simple extrapolation of today's technologies is not the most sensible and pragmatic ways of addressing issues concerning safe HRI [1]. As a result, ensuring safety and dependability of robots intended to interact with humans entails new approaches and perhaps a paradigm shift in designing and control of the new robots. In this regard, safe path planning and intelligent control algorithms are considered as the primary means of addressing human safety. This requires a clear definition of the safety and a quantitative index for measuring its value. To this effect, the level to which a robotic system is at risk is commonly assessed using a danger index [3]. A danger index can be defined such that it characterizes the impact force in potential collisions based on the distance to an obstacle as well as other factors such as velocity, inertia, momentum, and even human factors that affect the system [4]. Using a danger index in this context

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enables prediction-based path planning algorithms that unlike conventional distance-based planning algorithms (e.g., [5][6][7]) can incorporate the risk assessment into the planning process. Integrating the danger index into the path planning process enables the robot to respond to emerging dangers more intelligently. Several studies have shown the advantages of considering such danger indices in the path planning process for improved safety [3][8][9]. The research resulting at this conclusion is in-depth notwithstanding, there are two major issues that require further investigations. This includes (i) the necessity of respecting the principles of optimality in the optimization process of the new safe path planning algorithm, and (ii) the need for a computationally efficient yet accurate modeling technique that can be integrated with the danger evaluation. While, some well-known problems as getting trapped in local minima, failure in eliminating the danger posed by multiple obstacles, and slow convergence of the optimization process due to the curse of dimensionality can be attributed to the first issue, addressing the second issue will facilitate accurate modeling of obstacles with complex geometries, including human obstacles, and provide a better means to make maximum use of the robot workspace particularly in confined and constraint areas. The current study suggests a solution that partially address the first issue by streamlining some of the calculations in the optimization process and at the same time offers a new human body modeling method that is more suited for danger evaluations and safe path planning.

## 2 Contributions and Results

In this study, a human body is modeled as an unduloid-like surface with a variable cross section at various heights. The cross section is formulated using a modified representation of superquadric functions. These functions are great candidates for obstacle modeling since they provide a compact but geometrically accurate means of representing objects regardless of their shape complexity [10][11]. When used for human body modeling, the model provides an accurate method of calculating factors (e.g., minimum distance, relative velocity, robot inertia, etc.) required for danger evaluations without much computational burden. Unlike other methods that either compromise the accuracy of the model by using primitive shapes in modeling objects or suffers from complex and memory-hungry algorithms, the suggested method is well suited for most real-time robotic applications, specially those concerns with HRI. As for the safe path planning, it is shown that a great deal of the robot workspace can be saved allowing for either collaborative or individual operations of the robot and human in confined spaces. To this effect, danger-based path planning is formulated as a constrained optimization problem. The objective of the optimization is to obtain an optimum trajectory (in terms of the traveled distance) by locating a number of via points in the robot workspace, such that none of the danger measures evaluated for the links of the robot are violated along the obtained path. In this regard, obtaining an optimum number of via points is also considered as part of the optimization process. In order to streamlines the optimization process, the problem is divided to two parts so as to (i) obtain the number of via points, and (ii) locate the via point accordingly. While a geometrical method is proposed to speed up the optimization process, common issues such as local minima are avoided to a great extend.

The effectiveness of the proposed algorithm is evaluated on a 6 DOF CRS-F3 industrial manipulator. The results clearly illustrate the advantages of using superquadric function in modeling and subsequently in safe path planning. It is shown that the proposed approach significantly improves the performance of the system in terms of speed and accuracy by having a more accurate danger evaluation, while it performs much better in comparison to conventional methods in dealing with commonly encountered issues in this subject. The results

verify the suitability of the algorithm for real-time robotic applications with relatively large degrees of freedom.

### 3 Relevance to the Conference Theme

The main focus of the current paper is in the area of human-robot interaction, specifically, pre-collision safety strategies for a new breed of industrial manipulators intended to interact with humans. HRI is an emerging topic in robotics that introduces new application fields for industrial and non-industrial robots both in manufacturing as well as other sectors of the economy by bringing the robots closer to the humans. In this regard, the submitted paper presents promising results with great potentials for practical industrial applications involving HRI. As such, it is clear that the topic of the paper is very well in line with the theme of TePRA conference.

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