A Real-time Collision Risk Evaluation and Safe Control Method Using Pre-trained Deep Learning Model

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Abstract— **This paper presents a real-time collision safety evaluation methodology of collaborative robots in which the collision force and pressure are estimated by a trained deep learning model. Estimated values are compared with the allowable threshold required by ISO/TS 15066. In addition, we propose a safe velocity control algorithm that maximizes the velocity of the robot while ensuring safety based on the collision-risk evaluation results.**

I. Introduction

As the demand for collaborative robots rapidly increases, the potential risk of the collision during the collaborative operation between humans and robots is also increasing. To ensure the human safety, International Organization for Standardization (ISO) has stated the allowable collision pressure and force threshold for the human body parts that should not be exceeded in any situations including an unexpected collision [1]. Collision tests between robots and a measurement device designed to be dynamically similar to human body parts has been a typical way to judge whether a robot satisfies the safety requirements.

The experimental method, however, is not only very costly but also time-consuming to verify that the robot satisfies the safety requirements at any collision case even with tools of various shapes. For this reason, the simulation-based collision safety evaluation methods are recently studied. It would be practically more useful if the evaluation results are used to adjust the velocity of the robot. For this, a real-time evaluation capability is quite essential. The finite element simulation is not a practical approach because of its high nonlinearity in material property and the contact mechanics.

This paper introduces a real-time collision safety evaluation method based on a machine learning technique. The collision force and pressure that would be resulted in from a potential (or hypothetical) human-robot collision at the given time are calculated in real-time during the motion by using a deep learning model pre-trained with human-robot collision data. In addition, a safe velocity control method is described to maximize the velocity of the robot without violating the collision safety requirement given in ISO/TS 15066.

II. Collision Safety Evaluation and Control Method

In order to accurately evaluate collision safety using a machine learning based collision model, various accurate collision data sets that include all the effect of significant variables related to human-robot collisions are needed. The data sets to train the deep learning model are composed of inputs and outputs data. The shapes of the colliding parts, collision directions, the effective masses and velocities of robots and human body parts, stiffness of contacting surface of human body parts are the input data to the model. The collision peak force and pressure are the output variables. In this paper, a mathematical nonlinear human-robot collision model, which is extended from [2], is used in order to produce data sets for various inputs to train the deep learning model. For validation of the model, various collision experiments such as the free-fall test using a sphere impactor and a wedge impactor on the pig-skin and the collision test between a robot and a measurement device were conducted. The calculation time per a collision case using the mathematical nonlinear human-robot collision model [2] is around one second in MATLAB, which seems not feasible for the real-time use.

After the deep learning model has been trained with a collision data set produced by the mathematical collision model, the response frequency of the model for collision force and pressure estimation in MATALB was measured higher than 500 Hz. With the advantage of its high speed, it is possible to estimate in real-time the maximum safe velocity (MSV), which would be used as a reference velocity in the proposed velocity control algorithm shown as Figure 1. The use of MSV would significantly amplify the usability and productivity of the robot without sacrificing any safety of the human.

Details of the work and the results will be illustrated more in the poster.

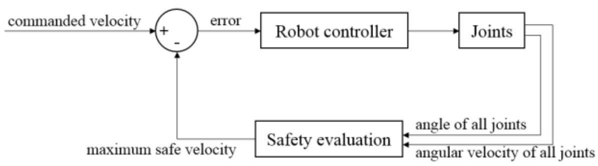

Figure 1. A block diagram of safe control algorithm.

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References

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