Collaborative Robot Safety for Human-Robot Interaction in Domestic Simulated Environments

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Abstract. Human-robot interactions carry several challenges, the most important being the risk of injury to the human. In industrial robotic systems, robots are mostly caged and isolated from humans in a safety guard environment. However, as time has passed, the use of domestic robots has emerged, leading to a high need in research on robot safety in domestic settings. Human-Robot collaboration is still in an initial stage; thus, safety assessments in domestic environments are critical in the field of collaborative robots or cobots, with simulations being the first stage of research. In this study, a preliminary investigation on the simulation of human’s safety throughout human–robot interactions in home surroundings with no safety fence is presented. A simulation model is designed and developed with Gazebo in the Robot Operating System, ROS-based, to simulate the human–robot interaction. In the robot trajectory, safety interaction can be simulated. In one example, the robot’s speed can be reduced before a collision with a human about to happen, and it can be minimized the risk of the collision or reduce the damage of the risk. After the successful simulation, this can be applied to the real robot in a domestic working environment.

Keywords— Safety, Human-robot interaction (HRI), Cobots, Trajectory, Robot Operating System.

1. Introduction
Robots have succeeded in increasing productivity and performing risky or monotonous activities in industrial settings. Research recently has focused on the potential for the use of robots to assist people in medical, workplace, or home environments beyond a purely "industrial” setting. The aging population in the developing world [1, 2] is an important motive for the use of utilities or personal robots. Robots are intended for daily living tasks [3] including dish clearing [4], load-carrying cooperation [5, 6], and feeding [7, 8], and social interaction [2, 9]. The marketing of robots for amusements [10] and home maintenance [11] is also growing. As robots switch from isolated working cells to unstructured and collaborative environments, knowledge about their environment needs to be better acquired and interpreted [12]. Security [13] and, more broadly, reliability [14] are one of the critical issues which hinder the entry of robotics into unstructured, human environments. Dependability includes physical safety as well as operational robustness, as described by Lee [14]. Some robots, mainly built for social interaction [9, 10, 15], prevent security problems under their
small size and mass and minimal manipulation. Figure 1 indicates the lack of a vital robot safety program which could lead to serious or fatal injuries to humans and loss of investment in capital in machinery [21] as well.

![Figure 1](image_url)

**Figure 1.** A conventional industrial robot with safeguarding devices preventing operator’s access to a workspace (Source of Robotics Industries Association) [21].

### 2. Related Works

Industrial safety standards [16] are designed to ensure protection by separating the robot from human beings, and thus do not extend to encounters between robot and human beings. Industrial experience has, however, shown that mechanical re-engineering is always the most powerful safety method for reducing risks [17]. This technique is often used for collaborative robots. For example, the whole-body viscoelastic robot was created by Yamada et al. [18]. Zinn et al. suggested to lower the effective inertia of the robot by using distributed parallel actuation. Although these and other mechanical re-design methods led to reducing the impact force during a collision, the collision is not avoided. Additional safety steps, the use of device control and planning, as illustrated in the following section, are necessary for secure and human friendly interaction in unstructured environments. Olawoyin [21] studied the safety and automation in the working environment in a collaborative robot system and concluded that efficiency must be optimized to escape safety constraints in safety-related issues in automation and robotics. Dombrowski et al. [22] stressed a certain importance for preparing human robot cooperation (HRC) in the automated factory devices. Weitschat and Aschemann [23] have established a new approach that still meets the international safety requirements of collaborative robotics for the improvement of robot performance. The method is focused on the projection of human arm movements on the robot’s way of estimating a possible collision with the robot and refining the method to achieve the target under human-in-the-loop limitations. Zhu et al. [24] have implemented a variety of approaches in which robots are stuck at a local minimum before achieving their target. The simulation annealing (SA) approach has evaluated an artificial potential field approach as one of the effective local minimal escape techniques. Simulated ringing for local and global route schemes has been implemented. Demir and Durdu [25] have reviewed the objective of human-robot relationship research in order to establish models of human expectations for robot interaction to direct robot design and algorithmic creation that make interactions between humans and robots more natural and efficient. Svante Augustsson et al. [26] demonstrated how versatile security zones can be enforced. In the case study the atmosphere at a wall construction site is emulated by an industrial robot cell using a robot executing nagging routines. Tests showed people entering the Protection Eye system monitoring areas. The zone violation was established and new warning zones started. The robot retracts, but continues its function at low speed and within a reasonable distance.
3. Methodology
Path planning for safety is a key component of an overall human robot contact secure policy. The robot can be better able to respond to unforeseen safety incidents by providing safety requirements at the planning stage. Planning is employed to boost the control outcome as a means of enhancing monitoring by using a smooth route design [27, 28]. A similar approach is taken here to [29, 30]. The possible risk requirements are however developed and evaluated using the proposed motion planning system in [31, 32]. Growing criteria specifically takes the user's inertia manipulator and mass centre into account in determining hazards. A two-stage approach to planning is meant to deal with possible overlapping planning requirements. In a simulation, the proposed plan is tested to compare the parameters and show their performance in an example handling mission.

3.1. System Overview
Figure 2 shows the flow chart of the system overview. Human-robot interaction can be two kinds of such as cobot and industrial robot, while cobot can be a mobile robot or arm robot. This research study focuses on the arm robot in domestic environments. The system will be realized using Gazebo, a simulator for robotic research. The safety model will be designed and developed using Python language, and the trajectory planning for the collision with humans will be investigated. In the end, the safety of humans to robot interaction will be assessed and validated by the model with a standard benchmark problem.

![Figure 2. Overview of the human robot interaction.](image)

3.2. System Design
Figure 3 illustrates the steps or process of this research work. In order to locate the safest configuration, the arm robot needs to pass successfully to the end-stage. If the arm robot cannot find any obstacle, then it is moved forward. Still, if it finds an obstacle, then it can be able to analyze what kind of obstacle is it if it is non-human, then it is moved backward. Still, if it is human, then the robot reduces its speed and check the risk factor of their interaction if there is no risk, then it is moved forward. Still, any risk is where it can be minimized the danger for that interaction moved forward and check the safety of the interaction. If the interaction is not safe, then the robot reduces its speed and stops after a while, but if the interaction is safe, then it moved forward. In the end, this algorithm
checks the goal of the research; if the algorithm is not achieving the goal it returns an error, but if it is achieving the goal, then the algorithm is run successfully.

Figure 3. Flowchart of the process of the study.

In order to realize the methodology proposed in this research work, a test simulation system is designed based on the experiment setup, simulation recorded for motion sensor without the object. Figure 4 shows a domestic environment and figure 5 represents the arm robot motion simulation on its trajectory in a domestic environment, while figure 6 illustrates the human and Robot interaction in a domestic environment, respectively.
Figure 4. A Domestic environment.

Figure 5. A robot arm in a domestic environment.
Figure 6. Human and Robot interaction in a domestic environment.

A domestic simulation environment is developed and illustrated in figure 6. In this environment, a human is placed, and it can move in 360° direction and forward and backward steps also, on the other hand, an arm robot is placed there which can move in 360° and three direction x, y and z-axis and also move forward and backward steps.

4. Results

4.1. Simulating Robotics Hardware
GAZEBO Player / Stage in ROS is a common simulation platform for robots. This system allows multiple robots to be tested in complex outdoor environments. A large range of sensors can be designed for each robot. These models provide practical feedback. The setting is modeled as a 3D world made of static objects, but can be moved by the robots. This ability is based on a simulation of rigid-body physics, which is also included in the structure, which allows for physically realistic interactions.

4.2. Simulating Human Characters
Robots are commonly used for simulation environments. Two main things have to be understood in case of such a simulation: firstly, the human model has to be animated, and secondly, the model has to be managed to be able to achieve realistic behavior. These simulations are not an interaction partner, they represent the robot itself. Motion capture devices also do not store movement rudimentary animation, but can be extended to a large number of human characters, for animation of interaction partners. There are various approaches to regulating human behavior. In order to evaluate the human character's actions, environmental information is used. The proposed system currently does not have a method to achieve the autonomous actions of the human character simulated. These features can, however, be considered a useful extension and realized as research for the future.
4.3. Simulation Framework

Figure 7 illustrates the simulation framework of this research. From the figure depending upon the environment, the arm robot stated, rewarded, and the agent takes the necessary action and briefly discuss below:

- The environment consists of where the two arm joints are in space
- The reward is the negative of the gap between the fingers and the target
- The actions consist of a real upward or downward movement on either of the two joints
- The state force raises the cup, hold a cup, lower cup used to activate protection.

4.4. Expected Outcomes

- The safety of human-robot interactions can be simulated: In figure 6, a human and robot interaction in a domestic environment are created. If the robot detects a human as an obstacle, then the robot reduces its speed and checks the risk factor of their interaction; if there is no risk, then it can move forward, but if any risk is still there, it tries to minimize the danger or stop there.
- The motion speed can be reduced: Using the Gazebo environment variable, the motion speed of an arm robot can be increased or decreased in real-time by using ROS-control and a necessary Gazebo plug-in adapter.
- The number of collisions does not exceed 2 out of every trial: Approaches such as Reciprocal Collision Avoidance (RCA) used by A. S. Matveev et al. (2016) [33] accomplished collision avoidance by assuming that each robot assumes some responsibility for each pair conflict, with the resulting constraints providing a range of variable speeds from which to choose using linear programming.

5. Conclusions

Visualization can be the first step towards gathering research results, before any implementation in the real world. In order to achieve the objective of this research study, a systematic process will be developed for ensuring safety during human-robot interaction in a domestic environment, based on an
explicit quantification of the level of danger in the interaction using ROS based gazebo simulator. Specifically, a method for assessing the level of risk at both the planning and control stages will be developed. Further, to accomplish the desired task of moving to the goal with a probability of collision with the human, evaluation trajectory fitness will be applied. In the end, the novel method will be investigated into physical system components that have been integrated and validated on a robot platform during real-time human-robot interaction and tested.

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References
[1] R. Bischoff and V. Graefe, 2004, “HERMES - A Versatile Personal Robotic Assistant”, IEEE, vol. 92, no. 11, pp. 1759 - 1779.
[2] K. Wada, T. Shibata, T. Saito, and K. Tanie, 2004, “Effects of Robot-Assisted Activity for Elderly People and Nurses at a Day Service Center”, IEEE, vol. 92, no. 11, pp. 1780 - 1788.
[3] J. M. Weiner, R. J. Hanley, R. Clark, and J. F. Van Nostrand (1990), “Measuring the Activities of Daily Living: Comparisons Across National Surveys”, Journal of Gerontology: Social Sciences, vol. 45, no. 6, pp. 229 - 237.
[4] A. J. Bearveldt (1993), "Cooperation between Man and Robot: Interface and Safety," IEEE International Workshop on Robot Human Communication, pp. 183-187.
[5] H. Arai, T. Takubo, Y. Hayashibara, and K. Tanie (2000), "Human-Robot Cooperative Manipulation Using a Virtual Nonholonomic Constraint," presented at IEEE International Conference on Robotics and Automation, pp. 4063 - 4069.
[6] V. Fernandez, C. Balaguer, D. Blanco, and M. A. Salichs (2001), "Active Human – Mobile Manipulator Cooperation through Intention Recognition," IEEE International Conference on Robotics and Automation, pp. 2668 - 2673.
[7] E. Guglielmelli, P. Dario, C. Laschi, and R. Fontanelli (1996), "Humans and technologies at home: from friendly appliances to robotic interfaces," IEEE International Workshop on Robot and Human Communication, pp. 71 - 79.
[8] K. Kawamura, S. Bagchi, M. Iskarous, and M. Bishay (1995), "Intelligent Robotic Systems in Service of the Disabled," IEEE Transaction on Rehabilitation Engineering, vol. 3, no. 1, pp. 14-21.
[9] C. Breazeal (2001), "Socially intelligent robots: research, development, and applications,” IEEE International Conference on Systems, Man and Cybernetics, Tucson AZUSA, pp. 2121-2126.
[10] Aibo Robotic Dog, Online: http://www.us.aibo.com.
[11] Roomba Robotic Vacuum Cleaner, Online: http://www.irobot.com
[12] A. Pentland (200), "Perceptual Intelligence," Communications of the ACM, vol. 43, no. 3, pp.35-44.
[13] P. J. Corke (1999), "Safety of advanced robots in human environments”, Discussion Paper for I-ARP.
[14] C. W. Lee, Z. Bien, G. Giralt, P. I. Corke (2001), and M. Kim, "Report on the First IART/IEEE-RAS Joint Workshop: Technical Challenge for Dependable Robots in Human Environments," IART/IEEE-RAS.
[15] Sony Orio. Online: http://www.sonv.net/SonvInfo/QRIO/technology/index5.html.
[16] Harper C, Virk G (2010) towards the development of international safety standards for human robot interaction. Int J Social Robotics Vol. 2(no.3): pp.229-234
[17] "RIA/ANSI R15.06 (1999) American National Standard for Industrial Robots and Robot Systems - Safety Requirements." New York: American National Standards Institute.
[18] Y. Yamada, Y. Hirawawa, S. Huang, Y. Umetani, and K. Suita (1997), “Human-Robot Contact in the Safeguarding Space”, IEEE/ASME Transactions on Mechatronics, vol. 2, no. 4, pp. 230-236.
[19] M. Zinn, O. Khatib, and B. Roth (2004), “A new actuation approach for human-friendly robot design,” presented at IEEE International Conference on Robotics and Automation, New Orleans, LA, USA, pp. 249-254.
[20] M. Zinn, O. Khatib, B. Roth, and J. K. Salisbury (2002), "Towards a Human-Centered Intrinsically Safe Robotic Manipulator," presented at IARP-IEEE/RAS Joint Workshop on Technical Challenges for Dependable Robots in Human Environments, Toulouse, France.
[21] Richard Olawoyin (2018), “Safety and Automation of Collaborative Robot System in Work Environment”, Robot Autom Eng J, Volume 3 Issue 3, DOI:10.19080/RAEJ.2018.03.555613.
[22] Uwe Dombrowski, Tobias Stefanak, Anne Reimer (2018), “Simulation-of-human robot-collaboration-by-means-of-power-and-force limiting”, Procedia-Manufacturing, vol.17, pp. 134-141
[23] Roman Weitschat and Harald Aschemann (2018), “Safe and Efficient Human–Robot Collaboration Part II: Optimal Generalized Human-in-the-Loop Real-Time Motion Generation”, IEEE Robotics and Automation Letters, vol. 3, no. 4.
[24] Qidan Zhu, Yongjie Yan, and Zhuoyi Xing (2006), “Robot Path Planning Based on Artificial Potential Field Approach with Simulated Annealing”, IEEE Sixth International Conference on Intelligent Systems Design and Applications (ISDA’06).
[25] Süleyman Demir, Akif Durdu (2019), “Human Robot Interaction in Indoor”, IJESC Volume 9 Issue No. 6.
[26] Svante Augustsson, Linn Gustavsson Christiernin, Gunnar Bolmsjö (2014), “Human and Robot Interaction based on Safety Zones in a Shared Work Environment”, HRI’14, March 3–6, 2014, Bielefeld, Germany. ACM 978-1-4503-2658-2/14/03. Doi: http://dx.doi.org/10.1145/2559636.2563717
[27] Julia Berg, Gunther Reinhart (2017), “An Integrated Planning and Programming System for Human-Robot Cooperation”, 50th CIRP Conference on Manufacturing Systems, Doi: 10.1016/j.procir.2017.03.318
[28] Macfarlane and E. Croft (2003), “Jerk-Bounded Robot Trajectory Planning - Design for Real Time Applications”, IEEE Transactions on Robotics and Automation, vol. 19, no. 1, pp. 42-52.
[29] K. Erkorkmaz and Y. Altintas (2001), “High Speed CNC System Design: Part I - Jerk Limited Trajectory Generation and Quintic Spline Interpolation”, International Journal of Machine Tools and Manufacture, vol. 41, no. 9, pp. 1323-1345.
[30] M. Nokata, K. Ikuta, and H. Ishii (2002), “Safety-optimizing Method of Human-care Robot Design and Control”, IEEE International Conference on Robotics and Automation, Washington, DC, pp. 1991-1996.
[31] A. Oustaloup, B. Orsoni, P. Melchior, and H. Linares (2003), “Path Planning by fractional differentiation”, Robotica, vol. 21, pp. 59 - 69.
[32] O. Brock and O. Khatib (2002), "Elastic Strips: A Framework for Motion Generation in Human Environments," The International Journal of Robotics Research, vol. 21, no. 12, pp. 1031-1053.
[33] Alexey S. Matveev, Andrey V. Savkin, Michael Hoy, Chao Wang (2016), “3 - Survey of algorithms for safe navigation of mobile robots in complex environments”, Book chapter of “Safe Robot Navigation Among Moving and Steady Obstacles”, Elsevier publisher.