Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 44 (2016) 187 – 192

www.elsevier.com/locate/procedia

6th CIRP Conference on Assembly Technologies and Systems (CATS)

Simulation platform to investigate safe operation of human-robot collaboration systems

Paul Bobka[a*], Tomas Germann[a], Jakob K. Heyn[a], Roman Gerbers[a], Franz Dietrich[a], Klaus Dröder[a]

[a]*Institute of Machine Tools and Production Technology, Langer Kamp 19, Braunschweig 38106, Germany*

* Corresponding author. Tel.: +49-531-391-7623; fax: +49-531-391-5842. *E-mail address:* p.bobka@tu-braunschweig.de

Abstract

In industrial human-robot collaboration (HRC) the question, how can such systems be designed safely is paramount. In general, it is difficult to assess those systems with all their capabilities prior to commissioning. In this paper we propose specialized simulation tools as one potential solution to this issue. We use real-world geometrical data to investigate different algorithms and safety strategies. One strategy is the use of a genetic algorithm for collision avoidance to deal with amounts of data in short computing times. This is a solution to find a safe distance with adaptive speed in HRC assembly applications.

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)
Keywords: Simulation, Human-Robot-Collaboration, Safety

1. Introduction

Nowadays, the international industry is struggling with declining product life cycles and increasing product diversification. Distinct products and thereby identical processes need to amortize in shorter time frames. This is an intersectional problem, which arises in the production of products in business-to-business and consumer markets. Frequently changing production orders are associated with high investment costs for the individual products. Conventional concepts for automation, which are optimized for maximum productivity, are reaching their limits. This is due to increasing demand for product and batch size flexibility.

Compared to specialized production machines, industrial robots represent a universal and more flexible automation approach. Those systems allow to implement different applications with less product specific investments. Therefore, industrial robots represent a flexible production system, which retains its value for the company even after a product change. [1, 2]

However, automation concepts with increased use of industrial robots are limited by economic efficiency for small production runs. Furthermore, the costs for implementation and modification are an obstacle for the process automation. It takes significant time (a few weeks up to years), depending on the complexity of the application, to provide an operational robotic work station. Due to this fact, a decision whether, and to what extent, automation is reasonable and efficient has to be made. Especially small batch sizes, which are usually done manually, are a financial burden in industrialized countries, since labor costs are high. A recent approach to overcome this problem are hybrid workspaces where robots are not separated by safety barriers and are collaborating with human operators in one workspace to combine human and robotic skills. The production approach, to use human-robot collaboration (HRC), has gained a great amount of research effort in recent years.

The consideration of safety is paramount in the research on human-robot collaborations. [3] It's one of the most crucial aspects in the implementation of human-robot collaboration systems in industrial settings. In relation to their productivity, HRC systems are classified between flexible, manual and robot based manufacturing. In high-wage countries, human-robot collaboration systems represent a new production approach, which encourages competitiveness. More research and development effort is needed to establish HRC systems in industrial applications. Research topics are: algorithms, sensor systems, simulation, process development, certification, as well as design of robots and tools.

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)
doi:10.1016/j.procir.2016.01.199

2. Related Work

In the current efforts to combine robots with manual human labor the safety risk is difficult to estimate. Modern robotic systems have a large number of functions and the direct contact between humans and industrial robots leads to complex system behavior. Because of this, it is difficult to certify human-robot collaborative work stations relating to their safety. Modern robotic systems such as KUKA LBR iiwa [4], ABB YuMi [5] and more, protect the human operator and themselves from dangerous forces, using direct or indirect torque monitoring. However, these systems only offer limited protection against sharp, pointed or detaching objects. Furthermore, force monitoring involves collisions or contact respectively to take effect, which limits the productivity of these systems.

Another focus of human-robotic research is visual sensor based monitoring and sensor guidance. A universal safety system, which is robot-independent, is the SafetyEYE made by Pilz [6] which enables an interference with the robots movement using virtual protected areas. It secures the process through visual observation of defined areas. If any of such areas is entered, the speed can be reduced or the robotic motion can be stopped. The safety certification of these safety systems is already complex and therefore expensive, more sophisticated systems face this obstacle to an even larger degree. A software specially developed for simulation of such applications could simplify and accelerate the safety certification.

2.1. State of the art

Flacco et.al. presented an approach using an Kuka LBR4 + and 3D depth camera to enable active evading with adaptive path planning as reactive behavior to human agitation [7]. This reactive and active behavior of the industrial robot enables new and diverse forms of human robot collaboration. The diversity is associated with complex system behavior, which cannot be adequately assessed in its safety according to the actual state of the art. In addition to vision based implementations of safety systems, ultrasonic, capacitive [8] or force [9] based sensors are developed for collision avoidance. Sekoranja et. al. [8]. for example, developed a capacitance based safety system to detect humans and static obstacles in close proximity to the robot. Since a collision can reliably be detected at an early stage, the speed of robotic movement can be increased in collaborative workspaces.

Another research focus for human robot collaboration is on the workspace design regarding ergonomic aspects, robotic tools, intention indication, simplified operation and economic aspects. Such technologies require certified safety functions for progression into industrial applications.

3. Guidelines and Standards

The relevant safety requirements for industrial robots are summarized in the EN ISO 10218, contactless protective equipment is classified in EN 61496. Furthermore, the Machinery Directive 2006/42 / EC and ISO 10218-1 and ISO 10218-2 can be applied to human-robot collaboration. The norm ISO 10218-1 includes safety regulations for industrial robots and ISO 10218-2 requirements for safe integration of robots. The ISO / TS 15066 is a technical specification specially for collaborative robots. This norm embodies for instance the design of the collaborative workplace, methods of collaboration between humans and robots, as well as information on the required minimum distances and the maximum robot speed. Furthermore, limits for the maximum allowable robot forces have been appointed in that norm. With the distance equation (Eq. 1) a safe distance between humans and robots in motion can be calculated. [10–13]

$$S = K_R(T_S + T_R) + B(K_R) + C_{Tol} + K_H(T_S + T_R + T_B) \qquad (1)$$

The braking distance of the robot is described by $B(K_R)$, where K_R is the speed of the robot, C_{Tol} is a factor that refers to the response characteristics of the sensor in terms of the viewing area, T_S indicates the response time of the sensor and T_R indicates the response time of the robot controller. The braking time of the robot is defined as T_B and K_H describes the velocity of the interacting person. Using all of these variables, the safe distance between the robot and the interacting person can be calculated. [13]

For a risk evaluation, the conceivable human-robot collaboration scenarios, have to be clarified The classification of the main types of contact for human-robot collaboration is shown in Fig. 1.

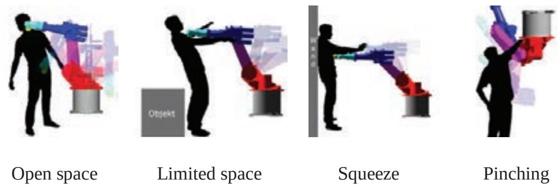

Fig. 1 : Contact classification between human and robot in accordance to [08]

Another classification can be made according to obtuse and acute application of force. In addition to collisions in open and limited space, it is often pinching or crushing actions, which lead to very serious injuries. [14]

The effective inertia and the speed of the robot is decisive for the seriousness of body injury in collisions in open space. Therefore, the HIC (Head Injury Criterion) can be considered. This criterion is used to assess head injuries. Using Equation 2 the HIC can be calculated, where $a(t)$ is the head acceleration, which is integrated within the observed time interval $(t_2 - t_1)$ and then normalized. [14]

$$HIC = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2,5} (t_2 - t_1) \qquad (2)$$

In addition, there are other criteria to assess and compare the severity of injuries. Another example is the use of the