THE COLLABORATION BETWEEN HUMANS AND ROBOTS IN THE INDUSTRIAL ENVIRONMENT

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Abstract: This study will describe how the robotics industry evolved increasingly and a new phase of advanced robotics has emerged, and the relation between humans and robots in the same workplace. Problems of designing safer robots in human-machine interaction systems are urgent research topics in the field of industrial robotics. Many of the problems in industrial robotics are related not just to technological issues, but also to human-robot collaboration also will be discussed as an effective method to tackle this issue is the invention of Collaborative robots.
Keywords: Industrial Development, Robots, human-machine interaction systems.

1. Introduction

Experts believe that the "industrial revolution" will change the whole world, not just the principle of production. In this case, we are talking about the fourth industrial revolution, or as it is called - Industry 4.0. If you do not go into the controversy of specialists, you can follow the opinion of Klaus Schwab [1], who divided the industrial revolution into four main trends: unmanned vehicles, 3D printing, advanced robotics, and new materials. In this article, more focus will be on advanced robotics.

If we look back at the history of the robotics evolvement, we can notice that the increase of the functionality of robots leads to raising of the number of their possible applications in various fields of human activity.

The creation of a robot was preceded by the idea of replacing workers with hard work, and the physical capabilities of the human body served as a model for them. The robot can be considered as a universal machine for performing mechanical actions. The functional diagram of the robot includes the executive system, the sensor system, the control device, and the external environment.

Today, Robots have progressed beyond their previous limitations, becoming more adaptable, mobile, and intelligent. As part of Industry 4.0, robots have become the driving force of automation where it has never been before. Unlike pre-revolutionary production methods, where the human operator and robotic complexes are separated according to safety regulations, sophisticated robotics and a collaborative human interaction system are used in production. the operator and robot work together in a single working environment [2]. In the future, automation of processes in the field of logistics, health, and utilities will be carried out by robotic systems.

Fig. 1. The Fourth Industrial Revolution

Considering robotics in general, we can find three directions. The first direction is industrial robotics in, particular, these are industrial reprogrammable and multi-purpose manipulators programmed in three or more axes.

The second direction is collaborative robotics. This is a new stage in the evolution of industrial robots, in which they are expected to interact intimately with people while remaining safe. These robots have a variety of sensors and visual systems built-inn. If a person approaches the zone of action of such a robot, for example, they will be able to modify the behaviour algorithm without harming the person. If it is a moving robot, it must either halt or modify its course once it enters the human motion trajectory.

Following the next step is service robotics, which includes transportable autonomous/semi-autonomous robotic complexes, such as collaborative robot manipulators, that are utilized in a variety of human activities. These are robots that do helpful work for humans and equipment, witexceptdustrial process automation jobs.

When defining a collaborative robot, according to the technical specification [3], it is largely about a collaborative working environment, not simply about the security measures and sensors of a collaborative robot. The core of establishing a pleasant setting for human and robot interaction is shown in this description of the collaborative working environment. From the perspective of a collaborative robot, a person is viewed as a mechanical colleague, and the robot's job is to aid and assist in the achievement of the goal. The fourth industrial revolution paradigm reflects this notion of the progression of human-robot inteinteractionsustrystry is undergoing tremendous changes as a result of the search for more flexible and efficient manufacturing. The shift from automatic manufacturing to Industry 4.0, which has primarily been promoted by Germany, or smart factories, which have been promoted by the United State, is based on the emergence of a new generation of systems that incorporate the most recent technological advances in information and communication technologies (ICTs), data analysis, and devices such as sensors or robots. As a result of these changes, the tasks that industrial robots may undertake are no longer limited to the transfer of things or other acts that are repeated. Instead, there are a growing number of tasks in which humans and robots collaborate to complete tasks.

Previously existing obstacles that maintained an inflexible boundary between human and robot workspaces must be removed to permit efficient collaborative work between a human worker and an industrial robot. Other forms of safety systems should be implemented instead so that collisions can be avoided by sensing barriers and their movements, applying suitable avoidance tactics, and minimizing human harm in the event of an unavoidable or unexpected hit. These changes in industrial work patterns are represented in the ISO10218 standard [3], which was updated in 2006 to reflect these developments.

A further update has been applied for this standard were focused on the above definitions, providing details on collaborative operation requirements, and cooperation task typologies.

Previous review articles in the area of safety in human-robot collaboration have been published [4]–[5].

2. Research Methodology

• A guideline for safety in an industrial robotic environment

For a deeper understanding of safety systems, this table gives a wide overview of the aims pursued by the safety systems, hardware and software systems that are employed, devices that are used, and the actions involved in each type of safety system.

Table 1. Classification of safety in industrial robot collaborative environments.

PRINCIPAL AIM	SECONDARY AIM	SYSTEMS: Software	SYSTEMS: Hardware	DEVICES	ACTIONS
SEPARATING HUMAN AND ROBOT WORKSPACES III	HUMAN ACTIONS RESTRICTED	No algorithms	Warning Signals	Optical, acoustic, light, signals	No actions
			Access Restricted	Fences, chains	
	ROBOT BEHAVIOUR MODIFICATION	Basic algorithms of control	Combination passive and active safety systems	Interlocking devices. Proximity, tactile sensors	Robot stop/reduction of velocity
SHARING HUMAN AND ROBOT WORK / WORKSPACES IV	QUANTIFYING LEVEL OF INJURY BY COLLISION IV.A	No algorithms	IV.A.1 Estimation of Pain Tolerance	Human arm emulation system.	No actions
			IV.A.2 Evaluation of Injury Level	Standard automobile crash-test.	
	MINIMIZING INJURY BY COLLISION IN HRC or DELIBERATE CONTACT (HRI) IV.B	No algorithms	IV.B.1 Combination of Several Mechanical Compliance Systems	Viscoelastic coverings	Robot stop/ reduction of velocity/ motion planning/ reduction of impact forces.
				Absorption elastic systems	
			IV.B.2 Light Weight Structures	Ultra-light carbon fibre, aluminum	
		Safety Strategies for collision detection IV.B.3	IV.B.3 Sensorized Skin	Tactile sensors	
			IV.B.3 Prioceptive Sensors	Encoders	
			IV.B.3 Combination of Sensors and RGB-D Devices	Force sensors, RGB-D devices	
	COLLISION AVOIDANCE (HRC) IV.C	Safety Pre-collision Strategies IV.C.1	IV.C.2 Motion Capture Systems	Sphere geometric models/ SSLs	
			IV.C.3 Sensors capturing Local Information	Capacitive, ultrasonic, aserscaner sensors, IR-Led	
			IV.C.4 Artificial Vision Systems	One/Several Standard cameras /Fisheye	
			IV.C.5 Range Systems	ToF laser sensor	
				One/ several range cameras	
			IV.C.6 Combination of Vision and Range systems	Standard CCD and range cameras	
			IV.C.7 RGB-D Devices	One/ seveal RCB-D devices	

Network computing

Cyber-Physical Systems

Human and Robot Workspace Disconnection robot arborists are considered to be large and heavy as they move at a high-speed rate. So, it is necessary to prevent any collision and harm to humans. by detecting human intrusions in the workspace with the robot and adjusting the robot workspace and behavior accordingly. a detailed pic is presented below explaining the three hazardous motions direction for robots along with acoustic signals, proximity sensors, pressure mats, and ultrasonic sensors

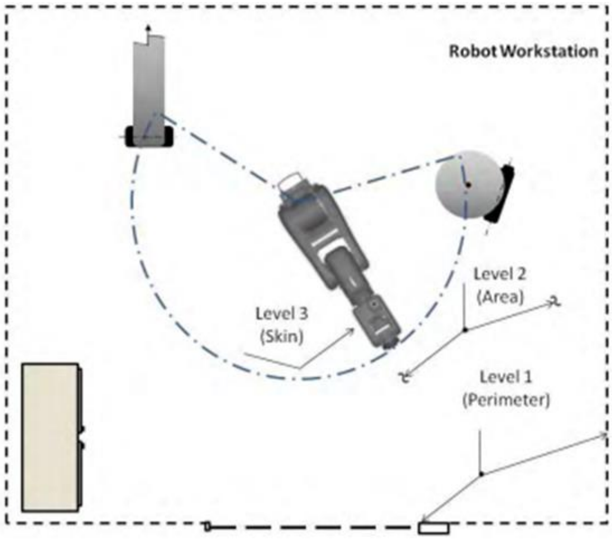


Fig. 2. Separating human-robot workspace.
A drawing based on [6]

Scenarios of collision between human and robot and its solution

In the following sections, the main ways to imitate these risks are presented, including the quantification level of injury by crashing. The information about the consequences to the human body of having such a collision with a robot is key information in taking the necessary steps to minimize injuries to the human and can be used for testing new robot safety systems.

3. Quantifying the Level of Injury Caused by A Crash

This issue may be discussed from two different points of view. The first one is to estimate the pain tolerance, and the second one is to estimate the level of injury after a collision.

1) ESTIMATION OF PAIN TOLERANCE

A study was based on the use of an actuator consisting of a pneumatic cylinder delivering impacts to 12 parts of the body of human volunteers to find a value of tolerable contact force. up to researchers have conducted their explements on humans to show the impact of forces coming from the robot in normal conditions, while others have modified this way to attempt to evaluate pain by replacing the individual in the experiment with a mechanical instrument. A passive mechanical lower arm (PMLA) was created for this purpose, and it was intended to be utilized in dangerous experiments, Fig. 3. (a). Human volunteers were used to assessing pain perception as well as impact force, velocity, and acceleration in robot-human collisions, which were then compared to measurements collected using the PMLA

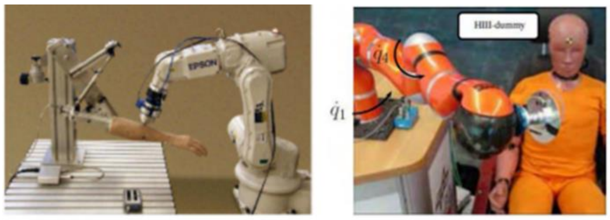


Fig. 3. (a) The PMLA and a six-axis robot in [7].
(b) Impact experiments with a light robot LWRIII and a dummy [7].

And here the researcher ended up using such a method as it is way safer than using volunteers when only the impact force and impact point speed are considered and evaluated, but not the impact point acceleration.

2) EVALUATION OF INJURY LEVEL

Because automotive collisions can damage the entire human body, automobile crash tests separate the human body into numerous sections to appropriately analyze injuries. The Head, face, neck, thorax, abdomen, spine, upper extremities, and lower extremities are the bodily areas described by the AAAM 1 [8].

Many injury indices developed by many researchers started from the Head Injury Criterion (HIC) and an equivalent division of body areas, and their related indices were defined by the EuroNCAP2. And another scale which is the Abbreviated Injury Scale (AIS) was proposed by the AAAM. The scale provides a classification of injuries by body region according to their relative importance, and it provides six categories from AIS-1 (minor injury) to AIS-6 (a maximal injury that can be considered fatal). In cases when several regions of the body are injured, the Maximum Abbreviated Injury Scale (MAIS) is applied, such that the area with maximum injury severity is used to define the overall injury severity. Finally, the adequacy of using injury indices developed by the automotive industry, including the HIC, in the human-robot collision context has been experimentally assessed.

Table 2 lists injury indices typically used to assess robot-human collisions, organized by body area of focus, as well as references to articles where the indices are referenced or utilized.

Table 2. Injury indices used to assess robot-human collisions.

BODY AREA	INJURY INDEX	REFERENCES
Head area	WSTC (Wayne State Tolerance Curve)	[9], [10], [11], [28], [35], [36]
	HIC (Head Injury Criterion)	[9], [10], [11], [23], [27], [28], [29], [30], [32], [33], [34], [35], [36], [37], [38]
	3ms-Criterion	[10], [28], [35], [36], [38]
	GSI (GADD's Severity Index)	[10], [27], [28], [38]
	MPI (Maximum Power Index)	[9], [11], [35], [38]
	MSC (Maximun Mean Strain Criterion)	[9], [11], [35], [38]
Chest area	VC (Viscous Criteria)	[10], [23], [28], [35], [36], [37], [38]
	Compression Criterion	[9], [11], [23], [35], [36], [38]
	Force Based Criterion	[9], [11], [23], [35]
	Acceleration Criterion	[11], [35], [38]
	TTI (Thoracic Trauma Index)	[10], [28]
Neck area	NIC (Neck Injury Criterion)	[9], [11], [35], [36]

4. Equations

Mechanical compliance systems and safety techniques using collision/contact detection are two types of methods that have been developed to limit the effects of crashes.

1) MECHANICAL COMPLIANCE SYSTEMS

This method has many systems to reduce the collision energy. Which are: viscoelastic coverings, absorption elastic systems, safe actuators, or lightweight structures.

a: VISCOELASTIC COVERING

A safety system for robot-human interaction is proposed in which the robot is outfitted with torque-sensing and linkages covered with a viscoelastic substance.

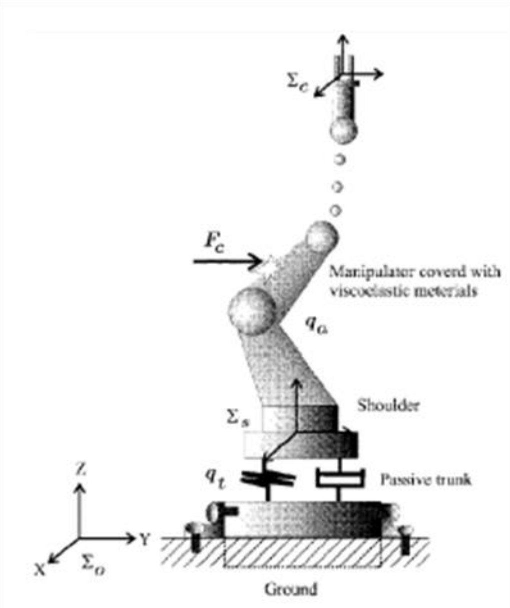


Fig. 4. (a) Conceptual model of a human-Friendly Robot HFR, [9]

The goal of this cover is to lessen impact forces while keeping contact. Viscoelastic coatings are also used as a suitable component for contact force reduction in [9], along with a deformable trunk consisting of springs and dampers, which is located between a fixed base and the robotic arm.

b: MECHANICAL ABSORPTION ELASTIC SYSTEMS

2) LIGHTWEIGHT STRUCTURES

With the development of systems for mechanical compliance, the use of lightweight materials such as light carbon _bres [10], and the use of sensor skin based on capacitive sensing developed by MRK-Systeme for Kuka robots or the capacitive skin developed by Bosch for the APAS robot the robots listed in Table 3 are suitable for collaborative human-robot tasks.

The properties of lightweight robot arms make them significantly more suited than typical robot arms for specific production processes that demand collaboration or interaction between humans and robots. In reality, many of the safety features addressed in this work, which are critical for safe human-robot interaction, are already included in current commercial lightweight robots. This is an important issue since the optimization demanded in Industry 4.0 also aims to decrease energy consumption in manufacturing processes

5. Collision Prevention

Further consideration should always to taken to prevent severe crashing scenarios so in this text few different manners have been posed to show the ways of preventing the collision as much as possible.

1) PRE-COLLISION SAFETY STRATEGIES

Different procedures have been taken through the different systems one of them [12] according to fig (6) we can differentiate three safety working areas based on the employment of technologies normally used to separate the robot from the human working area (photoelectric sensors and light curtains). The HRC safety design was designed and experimentally tested in a cellular production setting. The following is the safety technique, as shown in Fig (5): High-speed robot movements are authorized in zone A, which is the nearest area to the robots; low-speed robot movements are permitted in zone B, which is the middle zone; and robot speed is limited to less than 150mm/s in zone C, which is the furthest zone to the human.

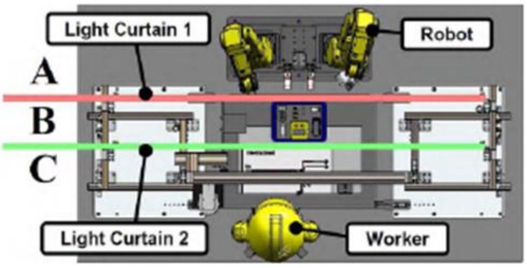


Fig. 5. Scheme of light curtains establishing three safety working areas in a cellular manufacturing operation, [12].

Another studied system in which RGB-D cameras are u to involve monitoring the work and estimating human-robot distances [13]. the area of a FRIDA robot attempts safety during collaboration. depending on the actions of robots two types of scenarios were shown. For the first one, the robot is in charge of self-driving behaviour, maintaining the programmed speed, when there is no person inside the workspace, but when there is a human inside the workspace the robot t switches to a collaborative model. So, this means when the human gets close to the robot area some constraints are applied, more closer approaching from the robot this means stopping or suspending the robot current task accordingly. After that when human leaves the area the tasks get to be resumed. The second scenario is similar to the previous one with taking into account reducing the speed.

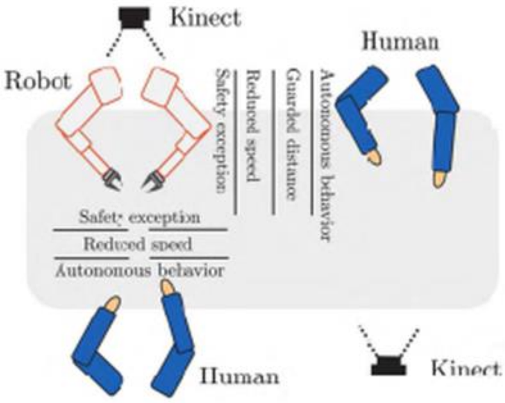


Fig. 6. Different robot behaviours in the experimental set-up for multiple HRC using RGB-D devices, [13].

2) SIMULATED AND MOTION TRACKING SYSTEM

This system was firstly initiated by using of UWB (Ultra-WideBand) localization system which uses the technique of triangulation of information from four fixed camera sensors located in the workspace and a small tag carried by the human to estimate the human position. Then it was developed with the bringing of axis-aligned Bounding Boxes (AABB) technology to distinguish three different areas of bounding volumes. Which gave good results when it comes to closes areas from the robot.

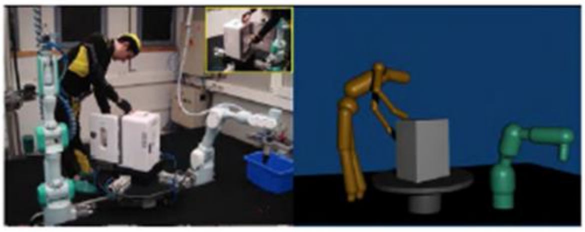


Fig. 7. Use of SSLs for an assembly task based on the cooperation of two robotic manipulators and a human operator in [14].

3) SAFETY STRATEGIES INVOLVING COLLISION/ CONTACT DETECTION

Mechanical systems are frequently linked to safety strategies involving collision detection that is used during human-robot collaboration, or to safety strategies that allow deliberate contact between human and robot, to improve the effectiveness of systems dedicated to minimizing injury in human-robot collisions.

Many studies and experiments had been conducted in the strategic case for example in human-robot collaboration situations, a unified approach for safety was presented and successfully tested through trials. The approach comprises a collision detection and reaction algorithm that pulls the robot away from the collision zone while allowing for purposeful physical interaction, which is their key contribution. Another one Magrini et al. [11] introduce the concept of motion and force control at any contact point on the robot and provide generalizations of classical impedance and direct force control schemes, which are implemented without the need of a force sensor, relying instead on a fast estimation of contact forces, Fig. 8.

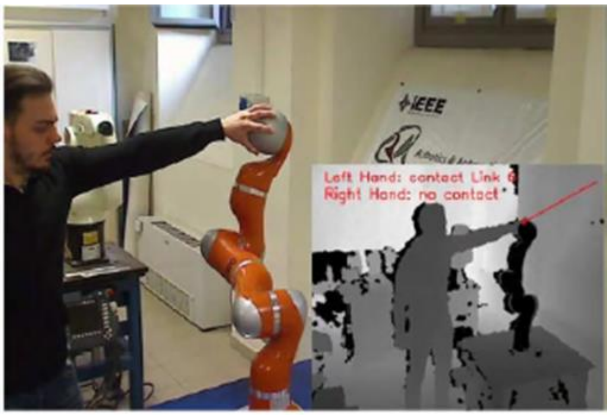


Fig. 8. On-line estimation of contact forces [11].

4) RANGE SYSTEMS

This system initially uses the laser stereo camera systems to get a full view of the 3D body in the area of study, based on the configurations of the robot and the expected route, and the detected obstacle, information can be gotten to avoid ca collision. a follow-up to the previous study, in which a general technique for surveillance of robotic settings utilizing depth images from conventional colour or aspect cameras is introduced. What the author found more interesting is that the information collected from numerous ToF cameras is combined to produce better resolution and less noise than that gained from a single camera.

Then the authors propose that several depth sensors be included as a way to reduce unmonitored areas created by the presence of objects in the scene. The presence sensor gives Boolean information, with each pixel set to true if an object is detected and false otherwise. A depth map is created by the depth sensor, which shows the distance between the focus centre and a detected item.

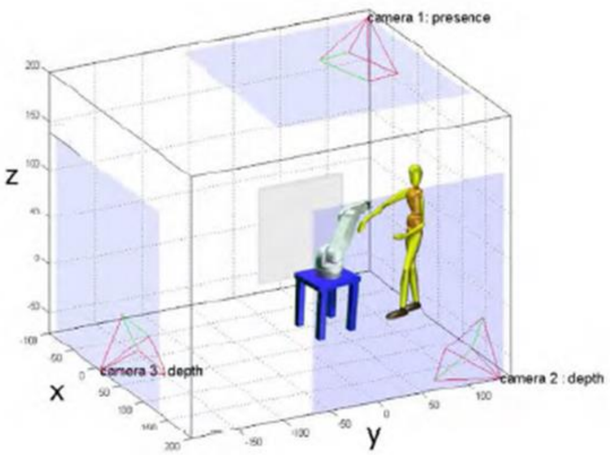
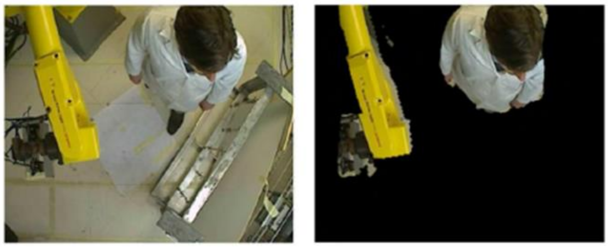


Fig. 9. A presence sensor and two depth sensors in their optimal [14].

5) INTEGRATION OF VISION AND RANGING SYSTEMS

A hybrid system based on a ToF camera and a stereo camera pair is explained and proposed used in HRC tasks. By generating a depth map that is mixed with the 3d data from the ToF cam, stereo information is being used to fix inaccurate ToF data points. The colour feature isn't taken into consideration. [15] presented information fusion as a method to extract 3D information from a robot cell and to be used in the detection of the proximity between a manipulator robot and a human using data captured by both a regular CCD camera and a ToF camera. Placement.

I would like to point out that no more cases have been studied related to other scenarios of crashing a wall or a beam. Most of the mentioned scenarios represent all the expected incidents in the work environment.



a) b)

Fig. 10. Foreground segmentation in colour images based on foreground detection of 3D points in [15]. (a) Original image. (b) Foreground segmentation in the colour image.

6. Results

This paper provides an analysis of safety systems and their use in robotic contexts, allowing collaborative human-robot work, including activities that need engagement. Changes in applicable standards have been addressed as a result of developments in the human-robot the connection that is reflected in global norms aimed at industrial robotic environments, which has included the integration of different definitions and the assessment of new dangers.

7. Conclusion

A very systematic way has been applied while doing this paper, where a detailed brief explained how robots are evolved synchronically with the presence of Industry 4.0 termination. What new hardware systems and their applications on robots effectively affected the usage of robots in a space where the presence of a human is a must and the good results achieved in that domain, taking into consideration the most precise details and scenarios to prevent any unexpected accident from happening.

8. Limitations

Despite the big achievement in the domain of enhancing the environment of human working incorporation with the Robots through different techniques, starting from Scenarios of collision, passing through mechanical absorption elastic system and ending up with collision prevention, it is undeniable that important work is yet to be achieved within Controlling unfilled obligations by teammates and handling implementation variance in ordering limitations not only this but other crucial questions need to be solved such as: What is the best way for a robot to learn how to breakdown complicated tasks? How can a robot and its human partners match these decompositions? How can a robot make needed skills more manageable to represent or perform by reducing their level of complexity?

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