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Human Robot Interaction in Collaborative Manufacturing Scenarios: Prospective Cases

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***Abstract*—Nowadays, robots are used extensively in manufacturing sectors because they improve quality and efficiency of production processes. Robots can perform various tasks autonomously with optimal working speed and accuracy. Even in a fully autonomous mode, a human operator is still needed to supervise operations and resolve issues, which led to an emergence of the collaborative robotics field. This paper reviews various potential industrial robots employed for human-robot collaboration and explores solution strategies related to safety during collaborative tasks.**

Keywords*—*Human-robot interaction, Industrial robot, Collaborative robot, review

I. Introduction

Currently, robots turned into an integral and indispensable part of modern human-robot interaction (HRI) activities [1], [2], automation of medical services [3], [4], urban search and rescue missions [5], agriculture automation [6], [7], transportation [8] and autonomous navigation [9], warehouse management [10], industry and production lines [11], [12]. Robots are deployed in industrial floors to assist or replace human operators for performing different types of repetitive and dangerous tasks. Robots are capable to operate with an optimal speed and accuracy, which help to increase quality and efficiency of production processes [13]. However, human operators are needed along with robots to supervise and control tasks to avoid unpredictable difficulties during the process. Human operators' integration within robotic operations eventually led to the collaborative robotics emergence [14]. Karabegovic *et al.* [15] promoted a shift toward the fourth industrial revolution by incorporating a larger amount of robots for accomplishing industrial processes. The key objective of the revolution is the emergence of intelligent factories consisting of robots, which can perform a wide variety of tasks without reprogramming [16].

II. Various Types of Industrial Robots

Industrial robotics is a rapidly expanding field due to the advantages of employing robots in performing various industrial tasks. A number of robots used in various industrial applications are increasing rapidly compared to the last decades [17]. Nowadays various tasks are carried out by robots, e.g., such as mechanical operations [18], handling and transferring objects [19] and assembly related tasks [20].

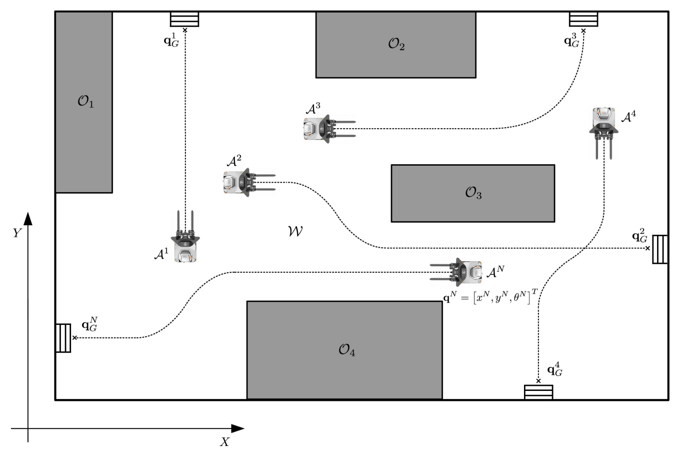


Fig. 1. Representations of Multi-AGVs used in industrial floor (borrowed from [21])

Transporting items to various locations inside industry is a major issue. Logistic items should be relocated and arranged in a specific order to complete the task effectively. Automated guided vehicles (AGVs) [21] are extensively used in industries to move items from one location to another. Importance of mobile robots in industrial tasks is proved by multiple researches such as vehicle routing [22], [23], scheduling [24] and automatic warehouse management [10], [25]. Fig. 1 illustrates different AGVs used in industrial floors to transport various items [21]. Fig. 2 shows the layout of an autonomous warehouse and operation of a Unmanned aerial Vehicle (UAV) inside the autonomous warehouse inventory room [10].

Manipulators are another category of industrial robots used for carrying out tasks. Manipulators with fixed and moving bases are widely used in industries as shown in Fig. 3 and Fig. 4. Fig. 3 and Fig. 4 depicts the manipulators with fixed and moving base respectively.

Apart from using developed robots, some industries are using custom robots to carry out specific tasks. For example, Hichri *et al.* [33] presented a custom created P-bot shown in Fig.5 used for manipulating and transporting payloads in industries. This robot along with other robots can aid in various industrial tasks.

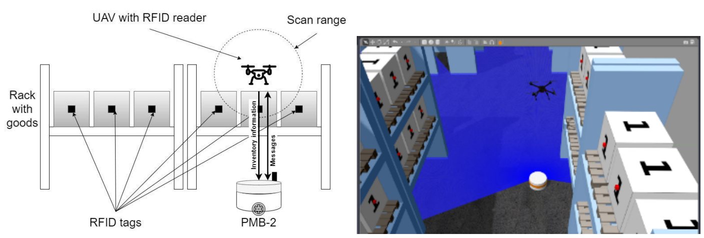


Fig. 2. Left - autonomous warehouse inventory operation architecture, right - the UAV takeoff and scanning of RFID tags at a goal point of the UGV (borrowed from [10])

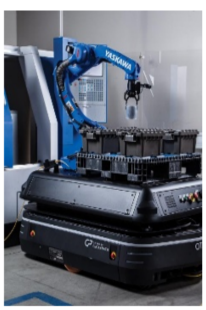
(a)

(b)

(c)

(d)

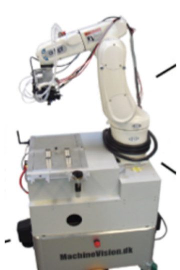
Fig. 3. Manipulator with fixed base(borrowed from [26]–[29])



(a)

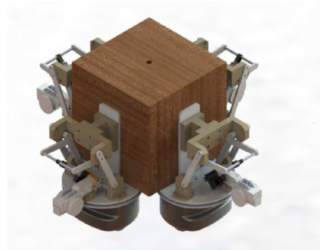
(b)

(c)



(d)

Fig. 4. Manipulator with moving base (borrowed from [27], [30]–[32])



(a) 3D CAD

(b) Manufactured prototypes

Fig. 5. Proposed design of the p-bot and manufactured system (borrowed from [33])

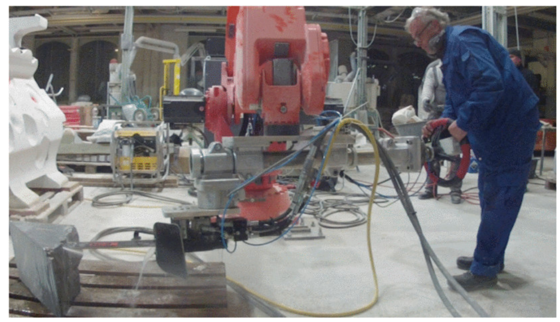


Fig. 6. Human-robot interactive stone carving task (borrowed from [35])

III. Applications of Industrial Robots

Various types of robots are used nowadays in manufacturing sectors for assisting human operators. Human operators are employed for scrutinizing the process to avoid the issues associated with operations of robot. In the following subsections some of the applications of industrial robots are explained.

Robots are widely used for carrying out industrial operations alongside human operators. Kana *et al.* [34] proposed a collaborative framework for carrying out chamfering and polishing tasks. The robot assists human operator for guiding the tool along predetermined trajectory. The proposed approach is found to be minimising the trajectory errors while operation. Another example for using a collaboration robot for carving stone to make sculptures is given by Vick *et al.* [35]. The robot assists the human operator for machining the stone blocks using diamond chain saw for making sculptures as shown in Fig. 6.

Arcadio *et al.* [36] presented an approach for the polishing of the surface for making plasmon resonance plastic optical fibers (SPR-POF) sensors using a human-robot collaboration method. The collaborative robot used for the polishing process is shown in Fig. 7. The process completed 70 percentage faster as compared to human labor alone and the polished surface is similar to hand polished surface. Hietanen *et al.* [37] demonstrated about a engine assembly operation carried out using human robot collaboration strategy. The work created a Augmented Reality (AR) based user interface (UI) for executing industrial assembly tasks. Fig. 8 shows the assembling task carrying out by Universal Robot (UR). In this experiment, UR is used for holding and positioning various engine parts whereas human operator tightens the bolts of assembled parts.

Palletizing is one of the most common tasks carried out by mobile robots employed in industrial sectors. This is the process of stacking goods on a pallet for transportation or storage. There has been a significant amount of studies carried out on robots performing palletizing operations in industries such as [38]–[41]. Murali *et al.* [38] introduced a flexible cooperation mechanism based on AND/OR

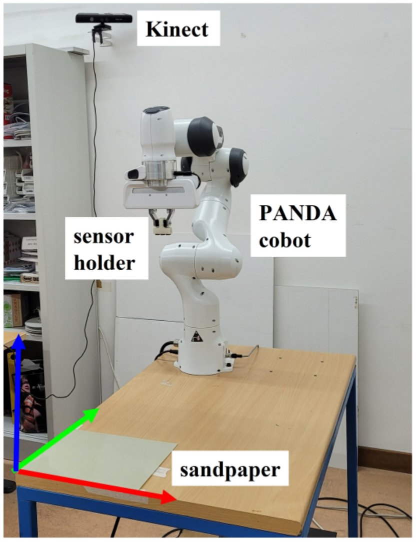
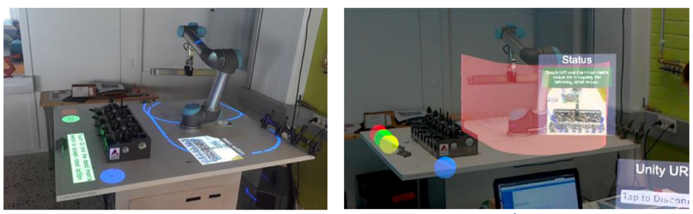


Fig. 7. The collaborative robot for sensor polishing with the reference desk frame (RGB convention) (borrowed from [36])



a b

Fig. 8. Interactive UI for safe human-robot engine assembly: a) projector-mirror and b) wearable (AR) HoloLens (borrowed from [37])

graphs. This article proposed an algorithm for industrial robots to grasp and inspect objects during Palletizing process. Lamon *et al.* [39] presented a collaboration work for Palletizing heavy parts in industrial environment. The robot is programmed to manipulate cargos alone or can move cargos in cooperation with a human operator for Palletizing. The collaborative Palletizing task is shown in Fig. 9. Krug *et al.* [40] demonstrated a fully autonomous grasping and Palletizing operations using APPLE (Autonomous Picking & Palletizing) research platform. Zhang *et al.* [41] tried to improve speed and accuracy of Palletizing robot used for position bolts using an improvised version of YOLO-V3 method. Kana *et al.* [34] proposed a collaborative framework for carrying out chamfering and polishing tasks. The robot assists human operator for guiding the tool along predetermined trajectory. The proposed approach is found to be minimising the trajectory errors while operation.

Comparison of various robotic configurations for carrying out different operations are given in table I.

IV. Safety Issues

One of the main challenges associated with collaborative industry is the safety related issues of employing human operator with the robot in same environment. Sensors along with precautionary methods are used together for ensuring safety during human- robot collaboration tasks. Some of the safety techniques adopted in human -robot collaboration tasks to avoid collisions are given in [42]–[44]. All of the above mentioned works focused on developing safe collaboration environments using various types of sensors and communication techniques. For example, Geravand *et al.* [42] presented a manual guidance strategy for avoiding collisions. The human operator

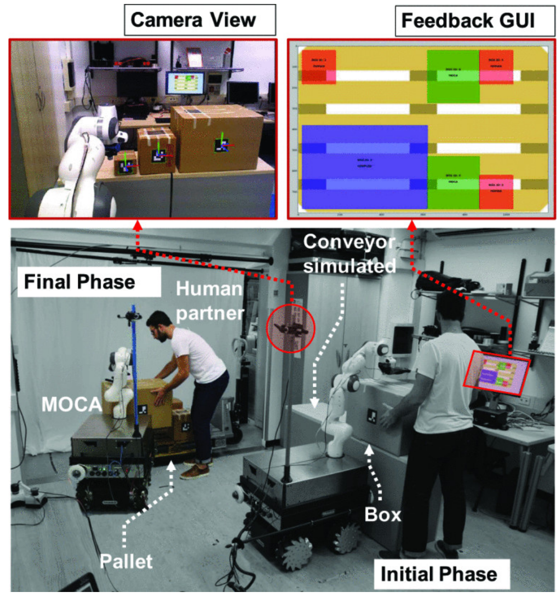


Fig. 9. Illustration of the experimental setup for the collaborative palletizing task (borrowed from [39])

TABLE I
Comparison of the robot configuration for different cases

Case	Mobility	Custom end-effector	Adjusted sensors
Basic human-robot interaction	no	no	yes
Polishing plastic optical fibers	no	yes	yes
Collaborative engine assembly	no	yes	yes
Autonomous palletizing	yes	no	yes
Machining processes application	no	yes	no

can apply force (push/pull) on robot during motion to avoid collisions. Costanzo *et al.* [43] used a multimodal perception method to avoid collisions during collaborative tasks. The method uses thermal and depth camera images to detect the presence of human operators. Escobedo *et al.* [44] detected the presence of collisions using onboard proximity sensors. The collisions are then avoided by incorporating a novel dynamic contact thresholding algorithm. According to lasota *et al.* [45], the system measures the distance between the human and robot positions by tracking the human hand using a specialized glove shown in Fig. 10. The robot speed is controlled for avoiding collision when the distance is reached below tolerance range.

Ragaglia *et al.* [46] implemented an approach using surveillance cameras installed above the working cell for evaluating the severity index in real-time experimentations. The methodology shown in Fig. 11 determined "Danger Index" (DI) software component to measure the collision chances. The system computes DI and sends the corresponding instructions to the robot controller. The proposed method is experimentally validated using an ABB IRB140 robot. Gecks *et al.* [47] used the camera images for avoiding collisions during collaborative tasks as shown . The method computes a path around obstacles comparing present images of the environment with

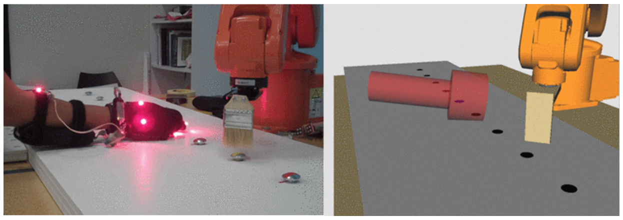


Fig. 10. Real workspace and corresponding virtual representation (borrowed from [45])

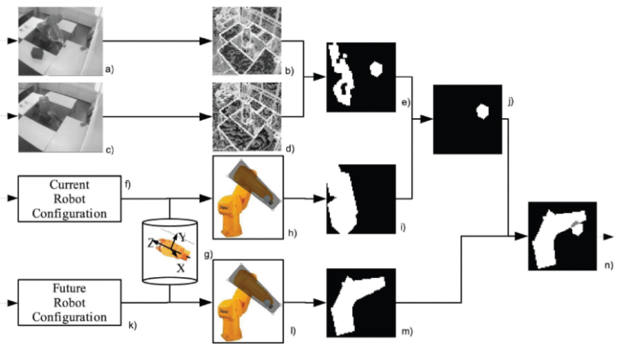


Fig. 11. Flow chart of the collision detection system with simplified computation steps (borrowed from [47])

reference images. The method detects humans and other obstacles via comparison of the current images to reference workspace images. Seci *et al.* [48] discussed about a real-time distance calculation method that enables safe human-robot interaction. A Microsoft Kinect V2 RGB-D sensor is used for capturing the 3D skeletal data of human operator as shown in Fig. 12. The experimental results proved that the robot can stop anytime during the operation to avoid collisions when the human enters the robot's workspace. Microsoft Kinect V2 is used for human motion tracking by Rosenstrauch *et al.* [49]. In this approach, Microsoft Kinect V2 along with an ultra sonic sensor is used for determining the operational area as shown in Fig. 13. The system tracks human activity and controls distance parameterized depending on the pre-segmented operating area between the robot and the human operator.

Anand *et al.* [50] presented a system based on passive infrared (PIR) sensors and ultrasonic radar for human activity detection. The PIR sensors are mounted on the ceiling on the top of the robot workspace. The ultrasonic radar is mounted on the manipulator's arm near the robot end-effector. Once human activity is detected by PIR sensors, the robot slows down to a safe speed limit of 100 mm/s as shown in Fig. 14. Based on the proximity of the operator to the robotic arm the technique allows an operator to share the workspace dynamically with the robot. Rybski *et al.* [51] proposed an approach based on the images obtained from stereo and range cameras. To provide the widest possible overlapping coverage of the area the sensors are mounted on the four upper corners of the frame as shown in Fig. 15. The approach fused data from multiple 3D imaging sensors of different modules into a volumetric evidence grid. Vogel *et al.* [52] presented a method for avoiding collisions using visual based method. The authors used a projector and cameras to implement the method. The projector establishes a safety region by emitting the images of robot into the environment. The image is generated using the current joint angles and velocities from the robot controller as shown in Fig. 16. When the safety line is crossed, the method generates a negative security signal to stop the robot. Rosenstrauch *et al.* [49] presented

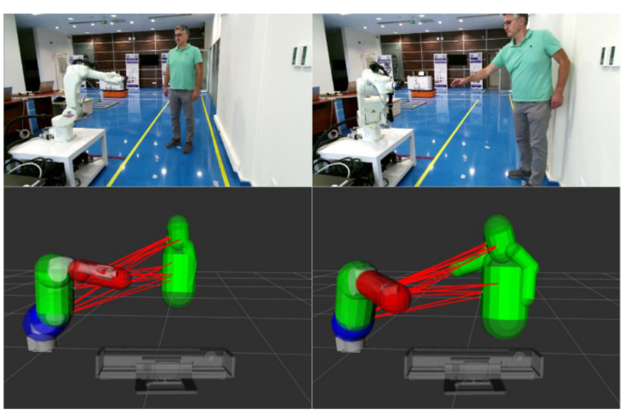


Fig. 12. The result of a minimum distance calculation between human and robot capsules on Rviz (borrowed from [48])

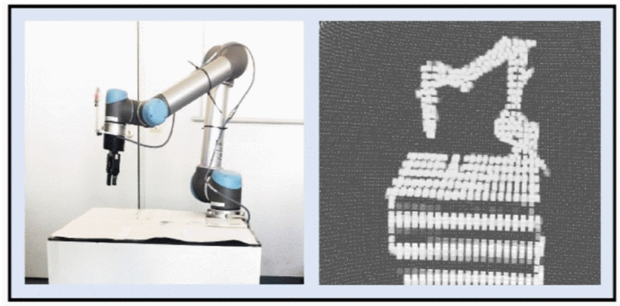


Fig. 13. Industrial robot and corresponding point cloud for a static case (borrowed from [49])

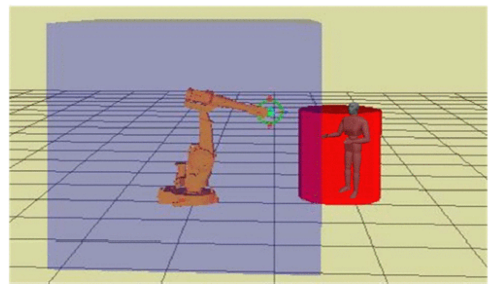


Fig. 14. The simulation environment consist of robot and human operator (borrowed from [50])

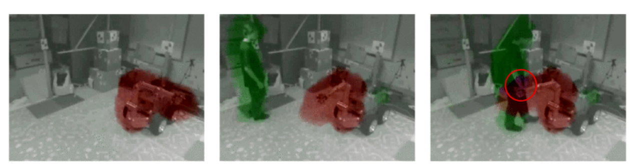


Fig. 15. An example of the approach proposed in [51]. (a) The workcell as seen by one of the 3D sensors. The red region indicates the adaptive danger zone surrounding the moving robot arm. (b) As the person enters the workcell, the green region indicates the adaptive safety zone surrounding the person. (c) When the person gets too close to the robot, the safety zone and danger zones intersect (shown in purple and highlighted with a red circle), and the robot automatically halts (borrowed from [51])

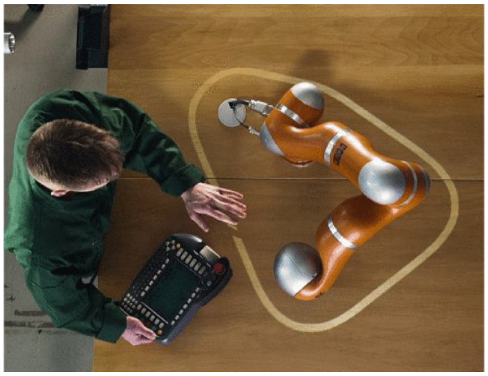


Fig. 16. Dynamically established safety space (white line) enclosing an industrial robot (borrowed from [52])

an approach to update trajectory of robot depending on the distance between the robot and human operator. The authors modelled a finite state method for the manipulation of robot behaviours. It consists of three superstates. The first is Safe area - where the distance between the operator/objects and the robot is larger than a pre-imposed boundary threshold. The second is Warning area - where the robot could end up in a collision, however the relative distance allows the execution of safe avoidance control algorithms. And the third is Danger area - where the distance is shorter than the one associated with a high collision risk. In the Safe area robot works without updating trajectory whereas in the Warning area robot checks collisions and modifies trajectory. Geravand *et al.* [42] illustrated a method for avoiding collisions and presence of human contact by measuring motor currents. The method allows the human operator to switch the mode of operation to avoid collisions. The article presents two case studies, the first study defines a method for manually driving the robot by applying force and second study defines the steps adopted by robots for resisting the applied forces on the robot body. The experimental validation of proposed method is carried out on KUKA KR5 manipulator as shown in Fig. 15. Table II compares different collision avoidance methods.

TABLE II
COMPARISON OF THE SAFETY SOLUTIONS

Case	Passive system	Active system
Camera & Phase-Space motion capture system	no	yes
Only Cameras	yes	no
Kinect	no	yes
Non-cameras solutions	yes	yes
Stereo and range cameras	no	yes
Internal motor data	no	yes
Projector	yes	no

V. CONCLUSION

Currently, a lot of research works are carried out related to collaborative systems. It has become clear that the majority of industrial operations can be completed more accurately and efficiently employing robots. As a result, industrial robots are either used for completing automation alone or in human-robot collaboration modes.The approaches mentioned in this article has benefits as well as drawbacks. And even while current level of artificial intelligence allows for the automation of some operations. However, human operators are still required to address non-standard problems and evaluate the workflow. This is the reason why developing collaborative human-robot systems seems more beneficial. The studies prove that in the nearest future number of the robots in manufactures will increase and industries are trying to incorporate fully autonomous robotic systems to increase the efficiency of industrial processes. Hence, human-robot collaboration methods are getting more acceptance nowadays.

This paper reviewed important aspects of modern industrial robots. Practical advantages of employing industrial robots along with professionally trained human operators were discussed. Different types of industrial robots and particular application cases analysis were presented. Safety issues associated with collaborative tasks and available solutions that increase safety were emphasized.

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