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A Survey on Applications of Human-Robot Interaction

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Abstract: Human-robot interaction (HRI) is the extensive research topic which aims at the complementary combination between the robot capabilities and human skills. The robots assist humans in terms of precision, speed, and force. The humans contribute in terms of the experience, knowledge of executing the task, intuition, and easy adaptation and learning, and understanding of control strategies. In this manuscript, a survey on the applications of HRI is presented. These applications could be industrial, medical, agricultural, servical, and educational. HRI can be found in industrial applications in handling of the workpieces in the production lines, co-manipulation tasks, welding processes, parts assembly, and painting. Assistive robotics are one from the highest profile areas in HRI. For people with the physical and the mental challenges, the robots can provide the opportunity of interaction and therapy. Furthermore, HRI can be widely applied in hospitals. Nowadays, HRI is very important to fight against the new coronavirus (COVID-19) pandemic. In agriculture, the robot is able to help humans with many tasks such as harvesting, seeding, fertilizing, spraying, weed detection, hauling, and mowing. HRI is quite new in the field of education. However, the robot can help children in classrooms for learning processes. In addition, the robots can help young children empathy and social skills. HRI can be found in other applications such as home use, inventory management, mining, Space exploration, and UAVs.

Keywords: Human-Robot interaction, Industrial applications, Medical and Rehabilitation applications, Precision agriculture, Education.

1. Introduction

HRI is the field of the study referring to understanding, designing, and evaluating the robotic systems used by or collaborating with the human operator. Interaction needs the communication between the robots and the humans. The human communication with the robot could take many forms. However, these forms are highly affected by whether the human operator closeness to the robot. Therefore, the communication or interaction between both the human and the robot is separated into two main categories [1-2]. The first category is the remote interaction and the second is proximate interaction. In the remote one, the human does not exist in nearby the robot. In addition, they are spatially or even temporarily separated. An example for this category is the Mars Rovers which is separated from earth in space and time as well. In the proximate category, the human and robot coexist in the same location. An example for this category is the service robots during their sharing with the humans in the same room.

These categories can help distinguish between the applications requiring the mobility, physical interaction, or social interaction. Remote interaction using mobile robots refers to the tele-operation or the supervised control. Remote interaction using the physical manipulator refers to the tele-manipulation.

Proximate interaction using the mobile robots takes the form of the robot assistant. Proximate interaction includes the physical interaction. In social interaction, the social and the emotive as well as the cognitive interaction aspects are included. In social interaction, the humans and the robots interact using the form of peers or companions. Importantly, social interactions with the robots take the form of proximate interaction rather than remote interaction.

From these categories, this manuscript deals with the proximate interaction. This manuscript is an extension to our previous paper [3]. It presents some real applications for HRI in industrial environment, medical and rehabilitation, agriculture, education, and other environments. Basically, these applications show the importance of the interaction happening between the robot and human operator in the real life.

The rest of this paper is divided as follows. Section 2 presents the industrial applications of HRI. In Section 3, the HRI in the medical and rehabilitation applications is presented. HRI in agriculture is demonstrated in Section 4, whereas Section 5 illustrates the HRI in education. Section 6 discusses some other applications of HRI. In Section 7, some methods for improving the HRI are discussed. Improving HRI leads to achieving the tasks and the applications easily and efficiently. In final, Section 8 concludes the main important points of this manuscript.

2. HRI in Industry

HRI is widely used in industrial applications such as picking and placing in the production lines, welding processes, parts assembly, painting, and so on.

Some examples for HRI in the industrial application are presented from Fig. 1 to Fig. 4. The robot workstation is running in the plant of BMW in South Carolina in which the robot helps human operators to perform the assembly of the final door [4] (see Fig. 1). In the door assembly operation, human operator and robots work together. BMW plant has succeeded to implement and develop the direct human-robot cooperation and interaction in the series production.

Human-robot teams are found also in the flexible production lines [5-6], as presented in Fig. 2. In this figure, the robotic manipulators and the human operators collaborate in handling of the workpieces. Safety is also is very important in such environments, since the proximity of the human operator to the robot that can lead to potential injuries.

In [7-8] a load of 1 kg is mounted to KUKA LWR robot end-effector to simulate a real case of transferring an object from place to place. The KUKA robot and the human operator are collaborating to transfer this object. In this case, the human hand guides the robot end-effector along a straight line segment motion via a variable admittance controller. This variable admittance control achieved higher reduction in the required human effort and the task completion time as well as higher increase in the achieved accuracy. This case is presented in Fig. 3.

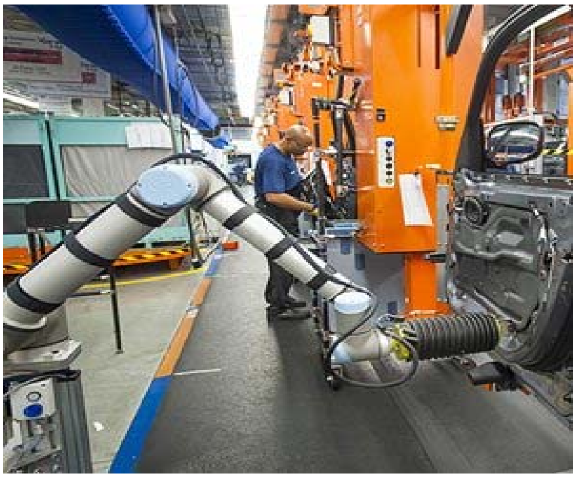

Fig. 1. The robot helps the human to perform the final door assembly in the BMW plant [4].

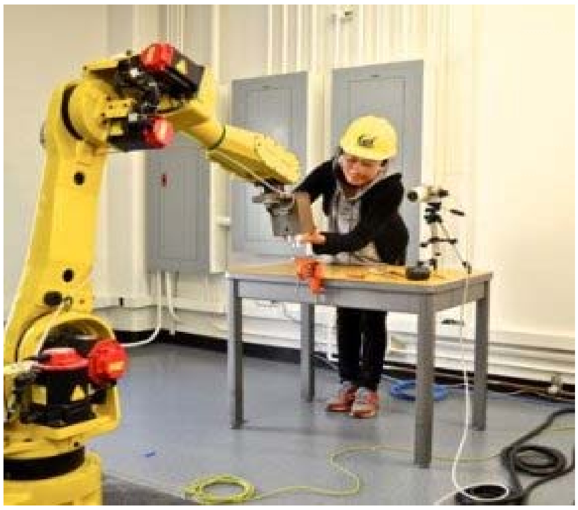

Fig. 2. The robot and the human workers cooperate in handling workpieces [5-6].

Fig. 3. The KUKA LWR robot and the human operator are collaborating to transfer an object (1 kg) [7-8].

Repetitive co-manipulation tasks as shown in Fig. 4 [9] can be performed in suitable poses of the human body. These poses can minimise the effects of the overloading joint torque. Furthermore, they can maximise the capacity of the manipulation of the human.

Another simple co-manipulating task is presented in Fig. 5 [8, 10]. In this task, the human arm and the manipulator are modelled as a closed kinematic chain (CKC). The selected task is a straight motion in which the robot end-effector is guided by the human operator via a constant admittance controller. The best location of the selected task is determined by the maximization of the minimal manipulability of the CKC along the path. The results from this approach succeeded to achieve the high velocity of the robot and the high human comfort, but in expense of the achieved accuracy.

Fig. 4. Example for the repetitive co-manipulation tasks [9].

Fig. 5. A simple co-manipulation task in which the best location of both the human-arm and the robot is determined [8, 10].

For handling of heavy and bulky components in welding situations, the multi-robot system with collaborative functionality assists the worker [11], as shown in Fig. 6. Two robots help position the components to be joined in the welding process, at which point the human operator carries out the welding task under favourable ergonomic conditions. In comparison with the standard welding bench, the human operator does not need to assume the uncomfortable postures or the work overhead. All necessary positioning and orientation of the workpieces can be performed by the robot. This also includes presenting of the components in the optimal position for the process of welding, allowing proper flow of the welding bead. Since the robotic repositioning motion is quite fast, the handling time which is about one third of the total process time is reduced to a minimum in comparison to welding processes in which HRI is not implemented.

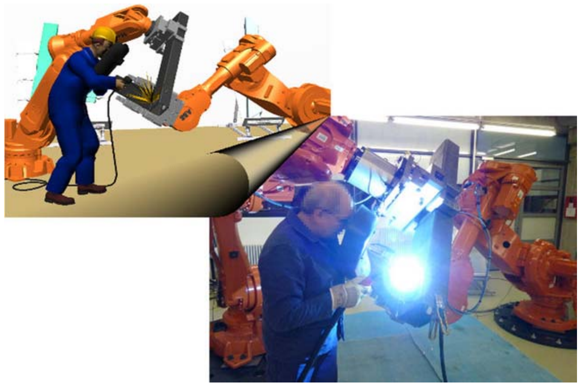

Fig. 6. The multi-robot system assists the worker in the welding process [11].

3. HRI in Rehabilitation and Medical Applications

Assistive robotics are one of the highest profile areas in HRI. For people with the physical and the mental challenges, robots can provide the opportunity for the interaction and therapy. This work is explored with autistic children in ref. [12, 13]. Many of them cannot respond strongly to the social cues but they respond very well to the mechanical devices. Robots give the possible therapeutic role for using the mechanical device for improving the social interactions [14]. Robots are being considered also for different domains in which children benefit, for example, children with experienced trauma. The social dimension of human-robot interaction is necessary not only in the assistive roles, but also in many areas and domains of the proximate interaction [15-19].

For people with physical disabilities, the robot embodiment provides the unique opportunities which are not possible with other technology forms. For example, the researchers are working on the design of the robots which provide and give the support for the physical therapy. Efforts include the providing of the prescribed force and the movement trajectories to help rebuild flexibility as well as strength [20]. Other work for detecting the motivational state and adjusting the therapy in order to maximize the benefits is presented in ref. [21]. Intelligent wheelchairs are the type of the robot which use the external sensors for supporting the path planning and the collision avoidance for the person that requires the wheelchair [22, 23].

An example of the rehabilitation robotics was presented in [24], in which, a robotic system was built as shown in Fig. 7, that performs correctly the exercise for the conventional physiotherapy such as the shoulder flexion, in similar way to what the physiotherapist do during the co-manipulating with KUKA LWR robot. In this way, the excellent characteristics of the human (the capacity of the decision, experience) and the robot (the precision, the work capacity, the speed, the force, and the repeatability) could be combined to achieve better results in the musculoskeletal rehabilitation of the arm. Furthermore, the second as well as the main objective was evaluating the non-pathological shoulder behaviour while performing the shoulder flexion movements.

Fig. 7. An Example illustrates the rehabilitation robotics [24].

The service or collaborative robots can take initiative to participate with nurses in decision making [25]. Based on that, Gombolay, *et al*. [25] conducted a successful test demonstration in which a robot assists the resource nurses on the labor and delivery floor in the tertiary care center (see Fig. 8). Furthermore, medical service robots can provide companionship for reducing the isolation felt by many older people [26]. In one study [27], a robotic companion was more successful than a regular plush toy at helping dementia patients communicate with their families.

Coronavirus disease (COVID-19) is the infectious disease which is caused by the newly discovered coronavirus. The severity of COVID-19 symptoms can range from mild to severe. The cooperation between the human and the robot help to fight against the new pandemic.

Two cases of the human-robot cooperation can be used in the hospital to fight against Coronavirus. The first can presented as follows. The robot can add the solution to the nasopharyngeal swabs from the patients for detecting the coronavirus genetic material [28]. The KUKA robot is used in the laboratory for making the tests (see Fig. 9), which greatly simplifies the test procedure. The positive test result illustrates that the patient is infected with the coronavirus. In that case, the samples which are taken from the patients' mouth, nose, and throat are tested for the genetic material of the coronavirus in the laboratory. The staff of the laboratory must only load the samples into the tray and then the COVID-19 test robot takes care with the pipetting.

Fig. 8. The robot system in action on the labor floor [25].

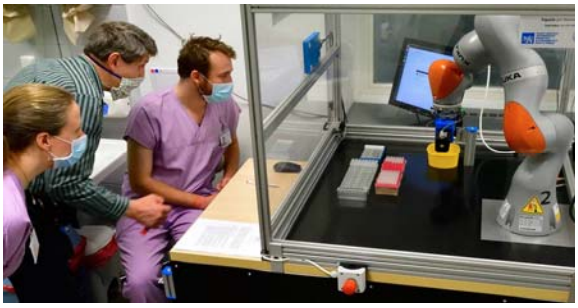

Fig. 9. The laboratory staff load the samples into the tray and the COVID-19 test KUKA robot takes care with the pipetting [28].

In the second case, a mobile unit is provided to the manipulator, as presented in Fig. 10. The mobile robot works hand in hand with the human and align to the workpiece with high precision.

Fig. 10. Mobile robot from KUKA [29].

The mobile robot can be used for providing the patients with the food and medicine. In addition, the robot can measure the temperature of the patients. This would minimize the direct contact between the patients and medical staff and others, and therefore, minimizes the infection potential. The robot can also help the humans for sweeping and washing the floors and the walls. This also minimizes the virus infection.

4. HRI in Agriculture

HRI strategies in agriculture are able to provide solutions to many complex problems, providing the security, the comfort, the lower workload, and also the better process productivity [30]. The cooperation between human and robot in agriculture helps with many tasks such as harvesting and picking, pruning, seeding, fertilizing, spraying, weed detection, hauling, mowing, phenotyping, and sorting and packing.

In the precision agriculture as presented in Fig. 11 [31], the robot helps the human-operator or farmer in picking the strawberry. In that case, safety between the human operator and the robot must be included. Furthermore, the robot was controlled remotely by a co-located operator. Their task was to navigate the robot to the location of pickers when they requested it, allow the filled crates to be loaded onto the robot, and then transport these to the storage facility. In Fig. 12 [32], intelligent robot is installed in the greenhouse to care and help farmers for the melon harvesting.

(a) (b)

Fig. 11. The Thorvald robot in the evaluation environment interacting with the pickers: (a) in the open strawberry fields, (b) in the polytunnel environment [31].

Fig. 12. The robot is installed in the greenhouse for helping the farmers for harvesting the melon [32].

Guy Coleman, a precision weed control scientist from University of Sydney, has designed a robot to help farmer for the weed recognition and control [33]. This robot might have application in broadacre agriculture. This designed robot has off-the-shelf sensors and the imagery equipment set up for targeting and identifing the weeds. This robot is presented in Fig. 13.

In Scaffold Mode, the concept of HRI is observed clearly. The human operator and the robot work as a collaborative unified system in which the vehicle autonomously navigates along the structured trees rows whereas the humans on the vehicle concentrate on performing and doing some activities such as 1) thinning, 2) pruning, 3) harvesting, 4) tying trees to wire. Tree trimming tasks were presented with Bergerman, *et al*. [34] and Freitas, *et al*. [35] (see Fig. 14) in which the humans working on the robot in the Scaffold Mode were able to trim trees more than twice as fast as humans using the traditional approach based on ladder.

Georgios Adamides in [36] developed an interface which allows the human operator for teleoperating a targeted pesticide-spraying robot, as presented in Fig. 15. This interface can command the robot to navigate along the vineyards rows. The proposed autonomy level is a semiautomatic teleoperation, which implies that the robot can work autonomously and remote manually if necessary.

Fig. 13. A designed robot to help farmer for the weed recognition and control [33].

Fig. 14. Human operators performing the tree trimming while standing in a robot [34, 35].

Fig. 15. The Agricultural robot sprayer [36].

5. HRI in Education

HRI is also effective and important in the field of education. The robot can help children in classrooms for different learning processes. The robot is used for promoting the education for the typical children, whether in the home or in the schools [37, 38]. Furthermore, the robots can help the young children empathy and social skills.

Caitlyn Clabaugh and her team [39, 40] developed the socially assistive robot (SAR) tutoring system (Fig. 16) for supporting the educators efforts to teach the number concepts to the preschool children. This system was designed iteratively with the input of the education experts for being developmentally appropriate. The system was investigated and tested in the real-world preschool classroom. The collected data were used for training personalized models of the number concepts learning, leveraging the multimodal data, domain knowledge, and also learning style.

The teaching assistant robot can help teachers as an educational media in class, and a classmate of the children for English learning (see Fig. 17) [41]. Basically, this can be accomplished with children in pre-school and elementary school.

Fig. 16. The tutoring system using robot for supporting the educators efforts to teach the number concepts to the preschool children [39, 40].

Fig. 17. The teaching Assistant Robot in English Language and Peer Tutoring Robot [41].

Chandra, *et al.* in [42] developed an autonomous system for assisting children to improve their handwriting skills, as shown in Fig. 18. Their system entails using the social robot in one-to-one learning sessions with children. The mode of interaction between the child and the robot relies on the peer-tutoring approach in which the robot acts as a learner and the child acts as a teacher. The writing of the robot was generated by the algorithm incorporating the human-inspired movements and could reproduce a set of writing errors. Their results showed that the children learn with the robot which exhibits learning competency.

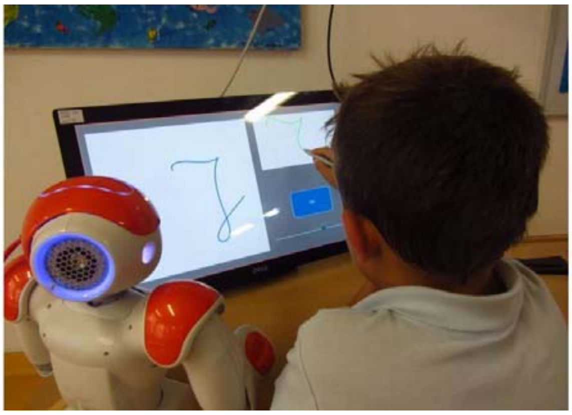

Fig. 18. A social robot for improving the handwriting skills of the children [42].

6. Other Applications

HRI can be found in other applications, which include service, home use, inventory management, and mining. In addition, Space exploration and UAVs are also some applications.

In home, the robot can help human in many tasks such as cleaning the floors and walls with sweeping and wet mopping functions, cleaning the windows and doors, preparing the foods in the kitchen, offering food and drinks to the guests, taking care with children, and so on.

The robot helps the human operator in mining industry as shown in Fig. 19 [43]. Using the robots increases the arsenal of the tools that help and support the miners to work in more safe and more efficient environment.

Fig. 19. The robot helps human in mining industry [43].

During the coronavirus outbreak, the robots are taking on a greater share of the work in some grocery stores starting from checking the shelves for low stock to helping in floor cleaning and moving inventory [44]. In Fig. 20 [44], the robot called "Pepper" is standing in front of the cash registers in the supermarket. The robot is informing the customers of the store about the rules of conduct in connection with the outbreak.

Fig. 20. The robot is informing the customers of the store about the rules of conduct in connection with the outbreak [44].

7. Discussion

In the previous sections, the applications of HRI in different areas in our real life are presented. For all these applications, highly efficient human-robot cooperation should be achieved. One of the main factors in HRI is safety, since the operator proximity to the robot can lead to potential injuries. Therefore, a system based on collision avoidance or detecting the collision should be found on the robotic system. Collision can be avoided by monitoring the environment using sensors as presented in [45-47]. Collision can be detected using model-based methods [48, 49] or using data-based methods [50-52].

Adapted controllers should also follow the human collaborator intention and the environment changes [53]. Therefore, this can lead to human-friendly robots and therefore the tasks can be performed easily and efficiently.

Searching for the best location of both the human operator and the robot can increase the speed of the co-manipulation task and the human operator comfort [10].

From this discussion, we can conclude that the methods for improving the HRI are very important and necessary for accomplishing the tasks and the applications easily and efficiently.

8. Conclusions

This manuscript has summarized some real applications of HRI. HRI could be found in industrial applications in picking and placing in the production lines, welding processes, assembling parts, and painting. Assistive robotics are one of the highest profile areas of HRI. For people with the physical and the mental disabilities, robots provide the opportunity for the interaction and the therapy. In addition, HRI could be commonly be widely applied in hospitals and nowadays HRI is very crucial for fighting against the new coronavirus (COVID-19). In agriculture, HRI helps with many tasks such as harvesting, seeding, fertilizing, spraying, hauling, weed detection, and mowing. HRI is effective and important in the field of education. The robot can help children in classrooms for different learning processes. HRI can also be found in other applications such as service, home use, inventory management, mining, space exploration, and UAVs. Methods for improving HRI are very important and necessary for accomplishing the tasks and the applications easily and efficiently.

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