ACS6503 Manipulator Robotics
Assignment 1 - Safety of Collaborative Robots

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1 Abstract

Development in various fields such as robot sensors, control technology, sensing the force, programming, environment recognition, human-machine communication, and safe system technology have made man-machine working possible in neighboring proximity. These modes of operations have abilities as it utilises both man and machine at the same time. In this document, the safety of collaborative robots is reviewed and analysed. The adaptation of sensory systems is discussed and future paths and safety concerns are suggested. Finally, a case study of collaborative robots is reviewed to justify the use of collaborative robot workspace, and a conclusion is drawn.

2 Potential modes of operation and and their characterisation

A collaborative robot is a robot that interacts with the human directly within the same working space, where both humans and robots are in close proximity. Collaborative robots are often called Cobots. The application of Cobots has been developed in contrast with the conventional industrial robots, which works in an isolated space kept at a distance from human contact. Cobots are made with light weighted materials, and they have an inherent property of speed and force limitations on sensors. The cobots are programmed in such a way that their behaviour is safe in the given environment. The operation of such robots can help reduce the work hours and workspace requirements. Both the human operator and the robot can coordinate with each other while handling and assembling heavy tools. This collaborative model of operation can give rise to economic advantages by bringing down operational costs. The application of Cobots includes information robots, logistics robots, industrial robots. For example, logistics robots transport materials within the same building (which automates user-friendly tasks).

The two important standards regulate the mode of operations in collaborative robots, they are:

1. **ISO 10218-1:2006** (updated in 2011) [1],[2]
   - part 1- Robots only (manipulator and controller)
   - part 2- Robots system / cell and application
2. **ISO TS 15066** is a technical specification that is designed as a guideline tool for the use of Collaborative Robots(released in 2016) [4]

2.1 ISO 10218-1:2006

ISO-10218 PART 1 [1] describes the need and the tools for guiding the safe design, use of industrial robots under preserved measures and details. It discusses the fundamental hazards while operating robots and furnishes requirements to manage the risks related to these hazards. This part of ISO does not apply to non-industrial robots. It includes the requirement of robot systems, that is, its assimilation and installation. Auxiliary hazards can be generated by particular applications such as welding, machining, laser cutting. These hazards must be kept in mind while designing a robot system.

ISO-10218 PART 2 [2] describes the safety conditions during the assimilation of industrial robots and their system and industrial cell as described in ISO-10218 PART 1. The assimilation process involves designing, manufacturing, installing, operating, maintaining, and decommissioning the industrial robot system. It also covers the components devices of the industrial robot system. The part mentioned above discusses the fundamental hazards and hazardous conditions marked within these systems and supplies information to reduce the risks related to these hazards. This part includes particular demands associated with industrial robot systems as a part of assembling and manufacturing systems. It does not include any hazards related to the processes such as laser radiation or smoke during welding.

2.2 ISO TS 15066

SO-15066:2016- This is a technical specification that describes the need for maintaining safe conditions for collaborative industrial robot systems and the workspace [4]. It provides the prerequisites and guides on the collaborative operations between the human operator and the robots mentioned in ISO-10218-2. It applies explicitly to industrial robots though its safety principles are helpful in several areas of robotics.

Under ISO-15066:2016, the collaborative of mode operation takes place, considering the following methods:

1. safety-rated monitored stop;
2. hand guiding;
3. speed and separation monitoring;
4. power and force limiting.

2.2.1 Safety-rated monitored stop

The Safety-rated monitored stop method is utilised to terminate the motion of the robots in the collaborative workspace when the human operator enters; otherwise, it finishes the tasks to be executed. In the absence of the operator, the robot works non-collaboratively. The activation of the system motion resumes without any extra interference but only after the operator has left the collaborative workspace. According to risk assessment, the protocols should avert an entry to the restricted place outside the collaborative workspace. Furthermore, the robot system should have sensors that can detect the operator's presence in the working space.

2.2.2 Hand guiding

Hand guiding permits the robot to move under the operator's control. In this method, the operator applies a hand-operated device to transfer the commands of motion in the robot system. It must be kept in mind that the safety-rated monitored stop must be active before the operator enters the collaborative space. The operation is done manually by activating guiding devices located near the robot's end-effector. Although the robot is powered, the operators are still protected because the robot's movements are under control. The robot system used for hand guiding is provided with additional characteristics such as intense force, devices used for tracking, and virtual safety zones. The steps involved in the Hand guiding operation are:

1. On entering a collaborative workspace, the robot system gets ready as soon as the safety-rated monitored stop is activated. Hence, the operator can enter the workspace.
2. As soon as the operator enters the workspace, it takes control of the hand guiding device. The safety -rated monitored stop is removed and the operator starts acting on the hand guiding work.

3. Now reverse happens that is when the operator releases the hand guiding device, the safety-rated control gets activated.

4. At the end when the operator leaves the collaborative workspace, the robot system recommences in the non-collaborative workspace.

2.2.3 Speed and separation monitoring

Speed and separation monitoring adjusts the movement of the robot respective to the operator's position. In this operation, the robot and operator move synchronously in the collaborative workspace. Risk is mitigated, maintaining a protective separation distance between the operator and robot at all times. When the operator enters the collaborative workspace, the speed of the robot is regulated. If the operator moves nearer, the robot system will stop eventually. If the operator moves away from the robot, the robot restarts automatically and maintains a safe distance. When the robot increases its speed, then the distance decreases simultaneously. So, the robot must have a safety-rated monitored speed function and a safety-rated monitored stop function.

2.2.4 Power and force limiting

Power & force limiting is the most applied feature of collaborative robots. If any physical contact between the operator and the robot happens intentionally or unintentionally, the robot should limit its force not to hurt the operator. The risk is mitigated through safety-related control system by keeping hazards related to the robot below the threshold values. The risk assessment determines these threshold values. Now considering the contact between the operator and the robot system, this can be divided into the following steps:

1. intentional contact condition which takes place during the operation.

2. accidental contact condition resulting from in-synchronous working but not because of any technical problem.

3 Potential sensing systems & operational configurations

The collaborative robots require sensors to execute their task properly. Sensors can be of different varieties depending on their usage. Nowadays, we observe the utilisation of force-torque sensors, collision detection sensors, safety sensors, part detection sensors, and 3D vision systems in most cobots to expand their operations and provide safe surroundings. The robot uses a force-torque sensor to sense the force it is applying with its end effect or that is the end of the arm. It is generally located between the robot and the tool to record the forces applied to. These sensors are used for assembly, hand-guiding, training while limiting the force applied. Collision detection sensors can sense the pressure on a soft surface and the robot receives a signal to constrain its limitations. Safety sensors vary from camera to laser scanner, which can detect any presence around it and acts accordingly. Part detection sensors are used in the robot's gripper to make sure the object is appropriately grasped. Furthermore, the 3D vision systems have cameras that focus on different angles with cameras or laser scanners to identify the third dimension of any object. 3D vision is widely used in industries such as Robotic bin picking of randomly placed parts.

3.1 Operational configurations and steps

The overall processes should be methodical to reduce the factors of hazards and risks for the operator and the following steps should be taken [1, 3, 4]

1. **Automatic**: In the automatic mode, the robot performs the tasks independently while maintaining all safeguarding and risk management features. The automatic feature halts in case of a stop condition.

2. **Manual**: In the manual mode, the operator controls the motions, axis torques and power primarily. It also manages the risk mitigation strategies which are discussed later.

3. **Monitor self-learning robots** : In robot learning technology, self-learning has taken a step forward. Next-generation robots can now learn from the surrounding environment and keep an eye on other activities with algorithms such as reinforcement learning. They learn new and efficient paths to complete the tasks instead of being limited to early programming. But before letting them in, the potential mainstream hazards must be assessed.

4. **Introducing guarding device in the collaborative workspace** : Sensory devices that can detect the presence of hazardous material in the collaborative workspace should be included in the workspace.

5. **Inspect the mechanical components for wear and tear** : To examine the potential internal issue of the robot sensory system, the inspectors need to check the robot system if it gives any alarming signal. Sometimes the outward appearance is not enough to detect. Any issue must be dealt with immediately and should be resolved before the system starts functioning.

6. **Examine electronic parts for their originality** : Sometimes the electronic parts are faked. Most of the robots are imported from other countries where the manufacturer and suppliers are not verifiable, and it is too easy to fall victim to such tricks. Fake electronics can create serious programming noise and have can affect functioning. Sometimes, it is impossible to find the error in the robots, which requires total disassembling and reassembling. One can search for spelling mistakes on the different parts for the noticeable marks of forgery merchandise.

7. **Counteract unauthorized or improper maintenance and installation** : The installation and maintenance of the sensory system are of serious concern. The robot system technicians must have proper training because if they fail to comply with necessary safety procedures, serious consequences may follow.

8. **Observe the fundamental human errors** : In the first attempt, users think about the errors when they start with the programming or installation level. During the operation, human faults can be too expensive. If the operator is not trained enough and lacks exact knowledge to run a robot daily, then a basic error can easily become a disaster. Workers who try to apply a quick fix to a robot can put themselves and others at vital risk.

4 Review of collaborative robot deployment

Since the last few decades, many industries have seen the inception of robotic arms in assembly and welding in manufacturing, automotive. These machines are similar; it is kept away from the operator to complete their tasks safely. The vast, massive parts in motion can cause personal injury or even death. So the company workers had to maintain a distance when the robots were running and hence shut them off when they were required to go close to them. Nowadays, these kinds of gigantic manufacturing robots have evolved in a new sphere called collaborative robots. Collaborative robots or cobots are a new epitome of manufacturing robots that are designed in a way that they can work alongside humans rather than in isolated spaces. The efficiency of cobots is the same as the larger robots complimented with the feature of sharing workspaces with humans. They are user-friendly, especially when in industries, they have limited floor area because they now do not need separate areas to keep everyone secure. Cobots are not necessarily uncontrolled, which means they still require human operators to regulate and operate them. They still need the safety conditions to be maintained. Cobots can be programmed and trained, and it remembers which tasks it needs to finish and perform in a sequence. However, the operator controls the robot's physical movements while running necessary tasks. Currently, cobots are found in every industry, from metal fabrication and packing to CNC(Computerized Numerical Control) machining, molding, testing, and quality control inspections. A variety of sensors are embedded beneath the robot's outer surface, which can detect the workers in close proximity. Its speed slows down to ensure workspace safety. When the question arises of which is the better choice, the traditional or collaborative robots, it is decided according to the company's needs. If the task requires more space, power, and speed, then traditional robots are chosen. Otherwise, if the job requires slower but specialized work in a collaborative workspace, then collaborative robots are used.

5 Case study evaluation: Case II

Benchmark Electronics is an electronics and manufacturing industry founded in 1979, having its headquarters located in Arizona, United States. The company in its Korat, Thailand operation has employed 1500 employees. The company provides engineering, manufacturing, and integrated technology solutions with original pieces of equipment. The company has started using Universal Robots such as four UR5 and two UR10e collaborative robots. The UR+ ecosystem helped to get a Vision device so that the cobots could be easily installed. These UR robots are programmed for two tasks. The first one is assembly, and the other is testing the satellite modem transceivers. The cobot raises the product during assembly and fixes it with a printed circuit board and a module before it transfers into an auto-screwing device. Then the product is scanned using a vision sensor is performed and registers with serial numbers. Ultimately, the product is covered with a radio frequency cover by the cobot. While testing, the cobot picks the product and places it on the testing machine. The cobot sends a command to lock the product safely, and then the testing begins. The test results are sent to the Benchmark system after 15 minutes; then, the cobot sends a command to unlock the product. These cobots can automatically change their positions and be programmed again for a separate task, but there would be changes in the production hours. There was a risk assessment during the setup, which resulted as low risk and safety guard was not needed which reduces the cost of companies renovation.

The advantages of introducing the cobots in Benchmark Electronics are:

1. Cobots are too flexible and easy to use, which makes redeploying and reprogramming easier to do a new task that changes the whole production process.
2. During the setup process, the workers were trained in programming and system integration, after which they were transferred to high-skilled jobs with more complexity in the assembly level.
3. The company saved an exceeding amount for the workspace renovation as no guarding was required.
4. Cobots features come with safety functioning; hence the risk is low.
5. The cobots reduce operational time and workspace wastes significantly.
6. The company Benchmark Thailand has improved their quality of the products with the introduction of cobots.
7. The company is expecting its return of investment within a short period of 18 months.
8. Better consistency is observed in the production with minimal human error
9. Operational efficiency has seen a 25% increase, and manufacturing area is saved by 10%.
10. The cobots cause a rise in business opportunities because it allows the product to be tweaked and improved with minimal change in the production pipeline.

6 Conclusion

Cobots usually have a high range of movement based on their degrees of freedom. The future of collaborative robots can be determined with the improvement of various types of sensors in the robot system to safeguard the whole workspace. The devices such as Laser scanners, collision detectors help in the workspace by protecting the workers in close proximity. Moreover, the cobots motor system provides feedback consolidated into the cobot and gives the cobot's arm position information to the controller. The whole Cartesian workspace to the end-of-the cobots arm is checked safely with given information. In robotics, it is the interaction of the large number of sensors that can make cobots work in open spaces with no guarding fences around possible. Though achieving a solution to such challenges calls for great mastery.

References

[1] Robots and robotic devices — Safety requirements for industrial robots. BS EN ISO 10218-1:2011

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[3] Polverini, M.P., Zanchettin, A.M. and Rocco, P., 2017. A computationally efficient safety assessment for collaborative robotics applications. Robotics and Computer-Integrated Manufacturing, 46, pp.25-37.

[4] Robots and robotic devices — Collaborative robots. PD ISO/TS 15066:2016