The University Of Sheffield.

Automatic Control & Systems Engineering

ACS6503: Manipulator Robotics Assignment 1 – Safety of Collaborative Robots

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Name: Nilsu Atlan

Registration No: 230221176

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Introduction:

Collaborative robot technology is a significant part of the evolution of industrial automation, combining the cognitive capacity of humans with precision and ability to perform monotonous actions of robots consistently. In the industry, collaborative robots, or "cobots", are created to simplify operations by adding a robotic element without fully converting it into an autonomous system. Accordingly, collaborative robots work in sync with humans in tightly intertwined work environments moving beyond traditional robotic systems that operate in isolation with safeguarding measures.

Collaborative robots can be applied to many industries including manufacturing and healthcare while providing efficiency in terms of task execution and precision, and flexibility in terms of adaptability to different environments. With the several advantages provided by collaborative robots, safety issues are introduced due to the common working environment. Safety requirements include being able to work with a human present in its range and complying with regulatory standards while maintaining the productivity of the operation. The potential risks of physical interaction and the unpredictable nature of human behaviour necessitate robust safety mechanisms and guidelines that range from the design, operation, and deployment of sensor technologies and control algorithms to workspace layouts and operational protocols. As the integration of collaborative robots in various industries continues to escalate, addressing and resolving these safety challenges becomes paramount.

This report aims to explore the health and safety aspects of collaborative robotics. It details the current state of safety standards and modes of operation, assess potential sensing systems and operational configurations, and review current deployments of cobots. Additionally, it includes an evaluation of a specific case study provided by Universal Robots, focusing on the safety considerations and potential improvements in collaborative operation modes. Ultimately, this report emphasizes the critical role of safety in the successful integration of cobots across various industries, while also contemplating future directions in collaborative robotics and advancements in safety systems, including emerging sensing methodologies.

Literature Survey:

Potential Modes of Operation:

Mode selector can be utilized for the selection of the necessary operational mode.

1) Automatic Mode: The robot autonomously executes pre-programmed tasks under active safeguarding measures. For safety, this operation is halted for any detected stop condition [3].

2) Manual Reduced Speed Mode: The robot is operated by human intervention as teaching, programming, programme verification and maintenance tasks can be performed in this mode. For safety this operation is performed with a reduced speed and when all workers are outside the safeguarded workspace [3].

3) Manual High Speed Mode: The robot is utilized only for programme verification with speeds greater than 250 mm/s possible. For safety, a pendant with functions to control and adjust the speed of the robot is provided. Due to the higher speeds implemented in this operation, it is performed when all workers are outside the safeguarded workspace [3].

4) Remote Access for Manual Intervention Mode: The robot is utilized only for diagnostics and remote testing without overriding local control restrictions [3].

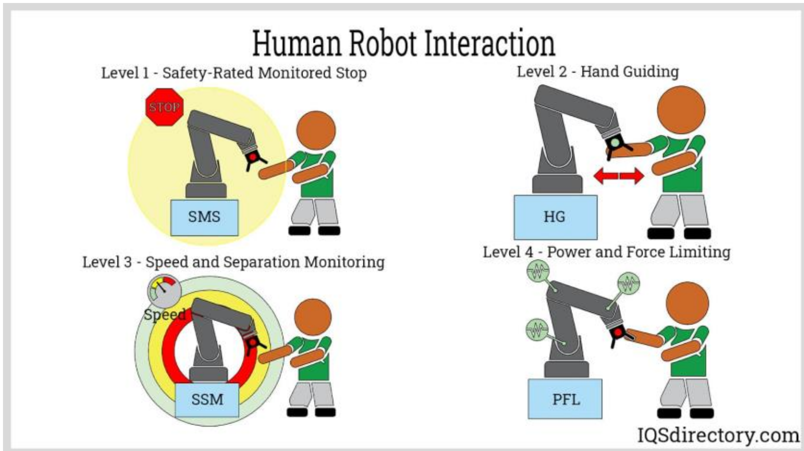

Figure 1: Potential Modes of Operation in Collaborative Robotics [9]

Operation modes related to collaborative operations are required for safe operation in human robot interaction.

1) Safety-rated Monitored Stop Mode: The robot can realize an obstruction of the workspace and perform a protective stop on its motion while keeping the drive power on. The robot can continue its non-collaborative operation after the obstruction is cleared [1].

2) Hand Guiding Mode: The robot's motion is led by an operator through direct interface. Safety-rated monitored stop mode is included in this mode as the operator obstructs the robot's workspace [1].

3) Speed and Separation Monitoring: The robot can reduce its speed when an obstruction is detected. Additional monitoring of the separation distance is present with sensors and vision operations while the speed is gradually slowed until the safety-rated monitored stop correlating with the separation distance [1]. The safe separation distance function is proportional to the approaching speed and the reaction time of the system.

4) Power and Force Limiting Mode: The robot reduces the risk of causing a human in the workspace harm by limiting the energy. This mode restricts the robot's exerted force and is designed to avoid pinch points and sharp edges, ensuring the robot safely complies upon incidental contact [1].

Each outlined mode above address different aspects of human robot interaction within collaborative environments emphasizing safety and functional efficiency in collaborative robotics applications.

Potential Sensing Systems and Operational Configurations:

Robust sensing technologies are crucial in mitigating safety risks inherent in collaborative robotics, to ensure secure interaction between robots and humans in a shared workspace. As specified in ISO-10218:1, these systems are integral to the functional setup of cobots and support various operational modes.

1) Vision Systems: Imaging devices, such as cameras, are employed by robots to perceive their environment. Recognizing where the human workers are located inside the workspace, monitoring, collision avoidance, human intention recognition and calculating the distance between points and obstacles are part of the purposes of vision systems [8]. These advanced systems are integral to the adaptability and responsiveness of cobots in dynamic industrial settings.

2) Speed and Separation Monitors: Continuously calculated distance between the robot and the worker in the workspace is used to calculate the approaching speed of the worker to the robot and visa versa. Accordingly, robot's speed can be adjusted to maintain a safe distance with speed and separation monitoring configurations [5].

3) Force and Torque Sensors: Unexpected resistance experienced by the robot can imply a safety risk for both the robot and a worker/object in the robot's workspace [13]. These sensors are critical in modes requiring power and force limiting, where excessive force or torque could lead to accidents or equipment damage. In hand guiding modes force and torque sensors are beneficial for the deliberate control of the robot.

4) Obstacle Detection Systems: Devices such as proximity sensors or laser fences are used to detect the presence of workers or obstacles, preventing collisions, and ensuring safe operation [7]. Pressure sensors could be used do the detection from the floor in addition to the contact detection with the robot. These sensing systems are efficient particularly in safety-rated monitored stop for disrupting operation when necessary.

These technologies enable a range of operational configurations such as safety-rated monitored stop, hand guiding, speed and separation monitoring, and power and force limiting, each tailored to specific operational needs. According to the information retrieved from these systems, the robots can trigger the appropriate safety mechanisms and this adaptability allows cobots to efficiently switch between modes according to task requirements and human presence, while upholding strict safety standards.

Current Deployment of Collaborative Robots:

The adoption of collaborative robots across industry is rapidly increasing, driven by their inherent flexibility and built-in safety characteristics. This section examines deployment of cobots, underscoring areas where they outshine traditional automation solutions.

Table 1: Comparing Collaborative Robots and Traditional Automation Solutions in the Industry [6][12]

Aspects	**Collaborative Robots**	**Traditional Automation Solutions**
Safety	Equipped with sensing systems, cobots can safely operate near humans, automatically adjusting to avoid collisions.	Require isolation and safety barriers from human workers due to their lack of safety features.
Adaptability	Ideal for custom manufacturing since they can be easily adapted to new tasks (beneficial for small and medium-sized enterprises (SMEs)).	Primarily designed for specific, repetitive tasks; less adaptable to varying operations.
Integration	Easily integrated into existing workflows, requiring minimal setup time. User-friendly programming	Installation typically involves extensive setup and potential disruption of existing workflows. Specialized programming
Cost	While initially costly, they offer long-term cost savings due to versatility, reduced need for safety infrastructure, and ease of re-tasking.	High initial investment with added costs for safety infrastructure and maintenance, particularly in specialized applications.
Space Efficiency	Compact design and the absence of need for safety barriers allow them to operate in limited spaces.	Larger and require additional space for safety barriers, making them less suitable for space-constrained environments.
Industries	Versatile across various sectors like automotive, healthcare, and logistics, performing tasks from assembly to assistive roles.	Confined to specific industrial tasks like heavy lifting, welding, or painting.
Mobility	Mobile	Immobile

As illustrated in Table 1, compared to conventional industrial robots that require isolation due to safety concerns, cobots are designed to blend into human-centric workflows.

Figure 2: List of Example Applications of Collaborative Robots [2]

As exemplified in Figure 2, in the manufacturing industry, cobots are used for tasks like parts assembly, working alongside human technicians to enhance productivity while reducing the strain of repetitive tasks and increasing precision [2]. Furthermore, in healthcare, cobots have found roles in laboratories for sample handling and in hospitals for assistive tasks, demonstrating their versatility.

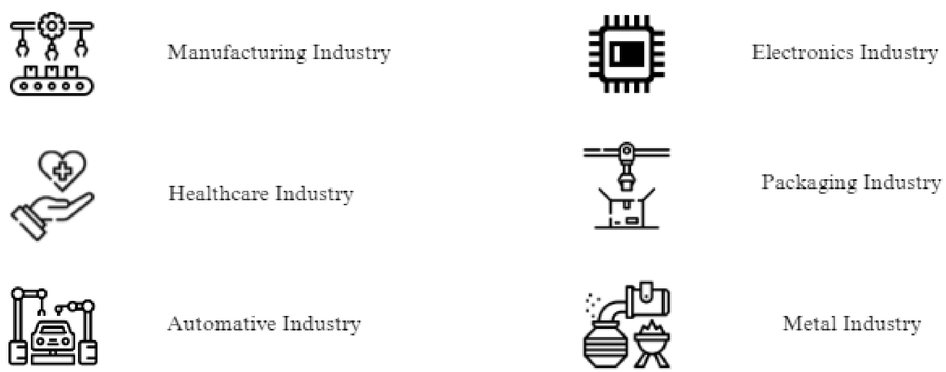

Figure 3: List of Example Industries Utilizing Collaborative Robotics

In summary, integration of collaborative robots is expanding due to their flexibility, safety, and ease of integration, proving them to be an asset in various industrial applications where they offer significant improvements over traditional robotic solutions.

Case Study: *Case 1: Napco Brands Using Universal Robots' Cobot (UR10e) in their Palletizing Systems*

This case study includes the implementation of the Universal Robots' "Automated Palletizing Solution" into Napco Brands' supply chain. The robot primarily operates in Automatic Mode, autonomously performing pre-programmed tasks under active safeguarding measures [11]. On the other hand, in Manual Mode operators can alter the task definition and program of the cobots with teach pendants. The robot either does not operate or operates with reduced speeds in these modes as the workers are in its range.

Safety Considerations and their Applications:

In terms of safety of industrial operations, there are many advantages of the collaborative systems. These systems handle repetitive and physically demanding tasks, notably reducing the risk of injury that workers face during manual palletizing (Universal Robots). To ensure additional safety during operation robots are integrated with advanced sensing systems. These systems not only facilitate collision detection and initiate emergency stops but also support a variety of operational modes, enhancing overall safety and efficiency. Another important aspect of cobots is their precision in operation not only for ensuring timely and accurate pick-and-place. By detecting any anomalies in the flow of boxes, for example, the robots can prevent potential mishaps or disruptions in the workflow. Such capabilities, as detailed in the Universal Robots e-Series User Manual, underscore the dual benefits of these systems in both enhancing safety and optimizing operational accuracy.

For Napco Brands, specific operational modes are implemented to balance safety, flexibility, and efficiency. Safety fences installed around the cobots, as observed in the video, enhance awareness and complement the operational modes.

Potential Improvements:

Further enhancements could include integrating flexible sensing systems to handle wider range of product types and sizes, adapting to different palletizing needs with minimal reprogramming or physical adjustments. Incorporating advanced vision systems could enable the cobot to perform additional quality control checks during the palletizing process, such as verifying label orientation or detecting damaged products. Implementing remote monitoring and control capabilities would allow for real-time adjustments and troubleshooting, enhancing the system's flexibility and responsiveness to operational changes. Tactile sensors could provide the cobot with the ability to detect subtle changes in texture or package density, further refining its handling capabilities. Environmental sensors, like temperature or humidity detectors, might be beneficial for ensuring optimal storage conditions during the palletizing process. Additionally, integrating auditory sensors could allow the cobot to respond to auditory cues or alerts in the workspace, adding another layer of responsiveness. Each of these sensing systems would contribute to a more intelligent and adaptable palletizing solution, capable of meeting the dynamic needs of modern production environments.

Different Modes of Collaborative Operation Applied:

Safety-rated monitored stops trigger immediate protective actions when humans are nearby, complemented by yellow visual alerts on fences for heightened awareness. The cobot's speed and separation monitoring enable fluid adjustments in its functioning, ensuring collaborative efficiency without sacrificing safety.

Additionally, modes that limit power and force permit close interaction between humans and the robot, while hand-guiding capabilities support detailed tasks in the shared work environment.

Conclusion: *Future of Collaborative Robots, Future of Safety Systems*

For the future of collaborative robots, it is evident that their integration into various industrial sectors will continue to expand and evolve. The key to this progression lies in the continuous advancement of safety systems and sensing methodologies, fundamental to the successful and harmonious integration of cobots in human-centric work environments.

Future safety systems in collaborative robotics are expected to become more sophisticated, with enhanced real-time monitoring and predictive analysis capabilities. These advancements will not only improve safety but also increase operational efficiency and reduce downtime. The integration of AI and machine learning algorithms could enable cobots to anticipate potential safety hazards and dynamically adjust their behaviour in response to human actions and changing environmental conditions.

In terms of sensing technologies, future cobots are likely to be equipped with more advanced and diverse sensors. These could include highly sensitive tactile sensors for more nuanced interactions with objects and humans, and next-generation vision systems with improved object recognition and spatial awareness. The development of sensors capable of detecting and interpreting a wider range of environmental stimuli – such as sound, light, and even chemical signals – will further enhance the adaptability and responsiveness of cobots.

Additionally, the future of collaborative robotics may see the development of more intuitive human-robot interfaces, making cobots even more accessible to workers without specialized training. This democratization of technology will enable a broader range of industries to leverage the benefits of robotics, particularly small and medium-sized enterprises. Finally, as the regulatory landscape evolves to keep pace with technological advancements, we can expect more standardized guidelines and best practices to emerge, further ensuring the safety and efficacy of cobot applications across various industries.

In summary, the future of collaborative robots is bright and filled with potential. With continued innovation in safety systems and sensing technologies, coupled with advancements in AI and human-robot interaction, cobots will become an even more integral part of the industrial ecosystem, driving efficiency, safety, and productivity to new heights.

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