Ensuring Safety in Industrial Robots: Issues, Consequences and Solutions

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Abstract – In this paper, a discussion of the safety issues in robotics are provided, categorizing them into three major origins: unfavorable environmental factors; human errors, and technical deficiencies. Information related to robotic accidents was retrieved from the Ministry of Employment and Labor (MOEL) and Korea Occupational safety and Health Agency (KOSHA) in Korea. Accidents are classified into root and direct causes, and these causes are reviewed through the application of the Systematic Causal Analysis Technique (SCAT). This research continues to emphasize that the risks, such maintenance of people, and robotic operations, are the most susceptible during interactions with robots. The research explores the classification of accidents in robots, causes of injuries, and the necessity for personalized safety measures. In addition, it presents a discussion of the lack of assurance, safeguards, and confidentiality aspect in robotics, and the detrimental effect this has on enterprises. Lastly, the paper highlights the effects of industrial robot mishaps, such as human injuries and casualties, data privacy and breach apprehension, and effects of corporate brand. It explores the safety concerns and measures from legislation emphasizing the necessity of establishing a balance between security and efficiency.

Keywords – Human-Robot Collaboration, Human-Robot Interaction, Safety of Industrial Robots, International Organization for Standardization, Small and Medium-Sized Enterprises

I. INTRODUCTION

In the modern age, the Human-Robot Interaction (HRI) field faces major challenges such as autonomy, acceptability, and safety concerns, as a result of the increasing need for robotics to effectively cooperate, support and interact with humans [1]. To effectively ensure accurate and safer engagement between robotics and humans, it is fundamental to establish and developrobots in a manner that reduces risks of accidents, such as property damage, injuries, and fatalities. Therefore, robots that engage with people may be classified appropriately. Various varieties of robots exist, which are often categorized based on their functionality, degrees of freedom, workspace, and other factors. These robots are generally divided into three main groups depending on their interaction with humans. The first category encompasses robotics where robots and humans are spotted separately, either temporarily or spatially. In this case, the HRI is limited and remote, and the robots necessitate a high degree of autonomy. The second category integrates Industrial Robots that interact with co-workers. The third one comprises Personal Service Robots that possess complicated, sophisticated, and close HRI capabilities, as well as an intermediate degree of autonomy. These robots are designed to aid elderly and disabled individuals.

Recently, there has been significance development in the establishment and marketing of collaborative robotic devices, including Universal robots, Baxter, ABB, and LBRiiwa [2]. These robots have the capability to enhance the skills of human workers by assuming repetitive and monotonous duties. By using robots, production is enhanced and human workers are afforded more flexibility. Given the prevalence of repetitive physical activities and the need for teamwork, the area of manufacturing is well-suited for Human-Robot Collaboration (HRC). Thus far, researchers have mostly concentrated their efforts on addressing safety concerns while developing new HRC approaches.The future of robotics is anticipated to experience a transition from the separation of humans and machines, towards a scenario where operators and robots work directly. This development gives rise to a safety issue, which is seen as one of the present issues in robotics: ensuring the secure connection between humans and collaborative robots. Implementing dependability strategies throughout the whole process of developing robotic solutions is an effective approach to enhance trust between collaborative robots and human workers. Dependability in a robotic system is achieved by adherence to ISO and Standards standards throughout the design and development process, as well as the robot's ability to operate alongside people without any malfunctions.

Given its crucial significance as one of the basic human wants, safety is an essential aspect of everyday existence. Due to the need of ensuring human safety, much study has been conducted on physical safety in the field of human-robot interaction (HRI). Physical safety in human-robot interaction (HRI) has been addressed via several methods, such as the use of human-robot collaborative control systems, the application of deep learning techniques, and the use of teaching by demonstration. A robot intended to cohabit with humans must prioritize safety, not just in terms of physical well-being but also in terms of psychological well-being.

However, there has been a tendency to disregard the way users perceive safety in both the HRI literature and safety regulations. However, the perception of safety is essential for establishing enduring contact, cooperation, and acceptance. In order to achieve acceptable HRI, it is essential for a robot to refrain from engaging in acts that may elicit discomfort, surprise, fear, or create an uncomfortable social scenario for humans, even if these actions do not result in any physical damage. There might be a disparity between the actual level of safety and the perceived level of safety. Wegman, Aarts, and Bax [3] did research which shown that even when accidents are avoided to guarantee physical safety, individuals may nonetheless have a diminished sense of safety. In addition, a review conducted by Williamson et al. [4] has indicated that only prioritizing the prevention of accidents does not consistently boost the safety perception of an individual.

Evaluating perceived safety of social robotics and households poses an additional challenge. People employed in the industrial field typically receive professional training before interacting with robots, but no training is required when handling residential robots, rendering them accessible to many people. In addition, vulnerable people, such as children and the elderly may use these robots established for home use. It is fundamental to provide much attention to the perceived safety during HRI because of the major emotional, cognitive, and psychological effects of these interactions. It is fundamental to identify these safety issues to effectively control them.

The main purpose of this paper is to provide a critical review of HRI and related safety issues. This involves identifying the main factors that contribute to these issues, such as adverse surroundings, human errors, and engineering flaws. In addition, this article explores the classification of injuries related to robotics, the effects of safety concerns on businesses, and control measures that can be deployed to enhance the safety of robot systems. The rest of the article is organized as follows: Section II presents a discussion of human-robot interaction. Section III reviews the safety issues in robotics, identifying the sources of injuries, endangered personnel, and classification of these injuries. Section IV discusses the effects of unprotected and insecure robotics; and presents a review of human injuries and fatalities, theft issues, data privacy and destruction of brand image. Section V focusses on safety measures and standards for industrial robots. Section VI presents a conclusion to the research on ensuring safety in industrial robots.

II. HUMAN-ROBOT INTERACTION

The concept of human-robot interaction first revolved on the teleoperation of robotic platforms in manufacturing settings. Telerobotics, as defined by Sheridan[5], refers to the direct and uninterrupted human control of a teleoperator, which is a machine that enables a person to extend their capacity to sense and manipulate objects to a distant place. He differentiates between telerobotics, which involves supervisory management of a distant machine, and semi-autonomous system supervisory control, despite the distance. Sheridan considers tele-robotics to be part of human-computer interaction. Human-computer interaction refers to the interaction between a user and a computer application, where the focus is on manipulating the program and its accompanying files, rather than controlling physical system via the computer.

The HRI extends beyond the remote control of a robot and enables the robot to perform a certain range of independent actions. This encompasses a spectrum of scenarios, ranging from a robot obediently following very accurate instructions from a human about the fine-tuning of acontrol arm, to a more advanced robotic system that strategizes and carries out a trajectory between a designated starting and ending point provided by a user. Recent advancements in robotics, particularly in sensing, reasoning, and programming, have made it possible to develop semi-autonomous systems, enabling the notion of human-robot interaction to emerge within the last decade. A workshop organized by the National Science Foundation (NSF),Department of Energy (DOE), and Institute of Electrical and Electronics Engineers (IEEE)addressed key concerns with intelligent machine assistants and human-machine interfaces. The difficulties included finding effective methods for a human operator to interface with many semi-autonomous devices. - Dynamic interactions and interfaces that adjust based on the specific roles being executed

Moniz and Krings [6] observed that robotic systems always require human expertise. Eguchi [7] argues that designers should use robot technology to augment and strengthen human talents rather than replacing them with robot skills. Mital and Pennathur [8] advocated for the advancement and use of robotic technology to enhance human productivity and efficacy, particularly by relieving people from monotonous or perilous duties. Hanna et al. [9] highlight that robotic researchers often prioritize matters regulated by regulatory mandates, such as safety. The neglect of human-centered design concerns has been prevalent. Kidd proposes that the human-centric design of human-robot interaction should extend its focus beyond technological concerns and include factors such as job distribution between humans and robots, safety, and group dynamics. It is important to address these concerns throughout the first phases of technological development. When the difficulties are only considered in the latter phases, they become less important and have little influence on design decisions.

According to Breazeal et al. [10], it is evident that there are advantages to be obtained when humans and robots collaborate as partners. However, it is essential for partners to actively participate in a conversation, inquire from one another, and collaboratively resolve issues. The authors provide a collaborative control system that combines the favorable features of supervisory control, while eliminating the need for human participation during a key time period. Collaborative control involves the human providing advice, while granting the robot the autonomy to choose how to use the information received from the human. The robot does not possess ultimate power; instead, it adheres to a higher-level plan established by the human, while retaining some degree of autonomy in its implementation. If the user can provide pertinent guidance, the robot may take action based on it.

Incase a user is not accessible within a specific duration of time, the robot will utilize pre-established measures to effectively address the issue. For effective collaborative control, a robot should be self-aware, self-sufficient, able to maintain its safety, able to communicate, and flexible. The management of user model and dialogue are fundamental in the application of collaborative control systems.

Research done by Burke et al. [11] highlights the necessity to integrate human factors into multi-disciplinary groups during HRI research. It is fundamental to highlight that HRI has a wider scope compared to just a smart user interface. To enhance productive collaborations across groups, it is critical to consider the capacity of both humans and robots, and to structure a comprehensive model, which permits every party to completely deploy their individual skills. The work at hand is challenging due to the incessantly transformative features of the modern robotic models. it is fundamental to cultivate HRI in an approach, which is now advantageous, which also assuring its flexibility to effectively accommodate futuristic advancement of robotic capability.

Robotics scholars typically employ the phrase “human-robot intervention” as a replacement for “human-robot interaction.”In the context of robotic systems with planning skills, the phrase “intervention” refers to the necessity for a human to make changes to a plan that has a flaw, or when the robot is unable to carry out a certain part of the plan. Although it is desirable for robots to do predetermined tasks such as cleaning the floor of the kitchen, monitoring the perimeter, or inspecting rooms on the 3rd level for X, it is also necessary for human-robot teams to engage in spontaneous interactions.

III. OVERVIEW OF THE SAFETY ISSUES IN ROBOTICS

To enhance safety in Human-Robot Interaction (HRI), it is essential to ascertain: a) the primary source of risk, b) the individual most vulnerable in the robot interaction, c) the possible repercussions of injuries, and d) the elements exerting the most significant influence on safety. Within this part, we systematically tackle each of these inquiries.

Sources of injuries

Robots may be classified into three primary categories: engineering flaws, human errors, and unfavorable habitat circumstances. Engineering faults include mechanical issues in the robot such as weak connections between components and defective electronics, as well as mistakes committed by the controller such as programming problems and improper algorithms. Thus, robots may have various shortcomings such as the inabilities to stop, or the robot arm may reach high speeds with sudden accelerations, or uncontrolled motion. The accident frequency stemming from these faults go beyond the capacity of even the most professional and careful human operator to predict. Contrarily, human mishaps that are more controllable occur as a result ofdifferentconditions, such as failure to follow safety rules, lack of attention, exhaustion, insufficient training models, or faulty processes during the first robotic start-ups. Adverse environmental variables involve conditions like high temperatures, inadequate sensing ability in challenging weather or lighting conditions, all of which could result in the robot providing inaccurate feedback.

Parsons [12] provide a detailed evaluation of various types of robotic accidents and the work environments in which these accidents tend to occur. Additionally, they provide data on the count of workdays lost by operators who sustained injuries in these occurrences. The data regarding robot accidents in this study were collected from the official data book on workplace fatalities presented by the Ministry of Employment and Labor (MOEL) in Korea [13], as well as accident investigation reports from 2009 to 2019 obtained from the Korea Occupational Safety and Health Agency (KOSHA). We have analyzed various statistical data obtained from the MOELwebpage, which regularly provides updated data on injury-related information, and IA on a monthly, quarterly, and annual basis. Furthermore, this study has gathered accident reports of investigation from the repositories of good product of the KOSHA webpage and has reviewed previously published research papers on robots to include relevant statistical information from the Occupational Safety and Health Research Institute (OSHRI) in KOSHA.

The robot accident data comprises detailed accounts of primary causes, accidents, and other factors related to accident. For instance, accident descriptions include details on the occurrence, including information about the timing, location, individuals involved, job activities, and procedures. The direct causes of robot accidents are the initial factors that lead to incidents in which operators are hurt. These causes trigger incorrect actions or unwanted outcomes. Root causes are underlying factors that lead to direct causes and may be identified by the analysis of direct causes and accident reconstruction. Thisdata is classified into categories such as accidents, works, and wounded body parts of operators. The causes of accidents are categorized into two types: direct causes, which involve root causes, and unsafe conditions and behaviors, which are related to factors such as the individual, the job, and the system. These causes are analyzed using the Systematic Causal Analysis Technique (SCAT), which was advanced by Det Norske Veritas (DNV) and incorporates concepts from James Reason's Swiss Cheese Model. SCAT is widely used in many corporate contexts, particularly in industrial industries, as a tool for root cause analysis.

Vulnerable workforce

The one who controls robots is the most vulnerable. Cheng, Lin, and Leu [14] provides a thorough investigation of 32 incidents, focusing on cause-and-effect relationships. The findings indicate that robot operators had injuries in 72% of the documented mishaps. Accidents were attributed to maintenance personnel in 19% of instances, while programmers had the lowest accident rate at 9%. This is directly proportional to the duration of a person's presence near a robot, as well as their degree of proficiency. Operators of robot are often trained to operate robots in predictable scenarios only, leaving them ill-equipped to handle unforeseen robot actions.

Maintenance staff often get more extensive training to effectively manage such unpredictability. However, in several scenarios, they are summoned after it is already established that the robot is not operating well. As a result, they retain a heightened degree of attention and exercise more caution. However, a significant number of maintenance personnel sustain injuries. Common causes of these incidents include human errors, such as when one member of the maintenance crew starts testing the robot system while another remains inside the robotic cell. The developers of the robot possess profound expertise in robot operation, resulting in their injuries being often classified into two distinct types. Typically, their injuries result from unforeseen glitches in the program. Occasionally, injuries may arise during the process of acquiring knowledge. Nevertheless, they have the capability to instruct and evaluate robots at reduced operational velocities, so reducing the probability of harm.

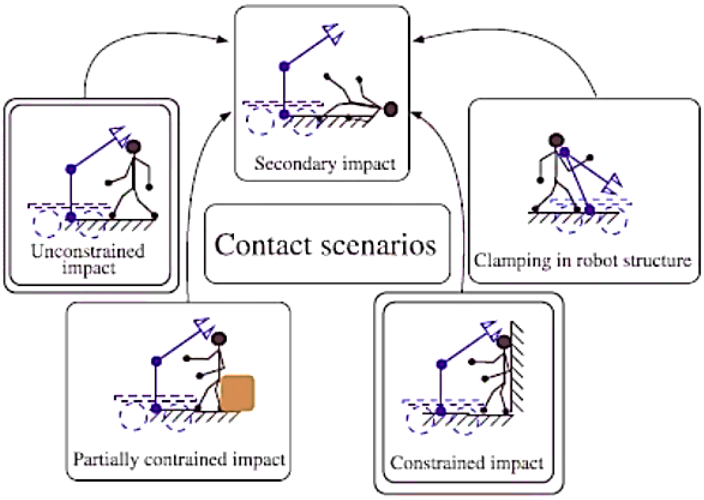

Fig 1. The Categorization of Undesirable Instances of Interaction Between Humans and Robots.

Categorization of injuries

The injuries in [15] are categorized according on their nature, with pinch injuries accounting for 56% and impact injuries accounting for 44%. A pinch injury is the result of a worker being caught between a robot and an item, whereas an impact injury happens when a worker and a robot clash. Consequences are categorized into three groups: mild injuries without any impact on work-time, injuries resulting in missed work-time, and fatal injuries. According to the findings presented in [16], pinch accidents seems to be severe compared to impact injuries. A more contemporary methodology by Haddadin, Albu-Schäffer, and Hirzinger [17] provides a more comprehensive categorization of contact circumstances that have the potential to result in an accident. Contact may occur in several forms, including clamping in the robot structure, unconstrained impact, confined impact, and partly constrained impact. **Fig 1** illustrates these instances. Each of these hits may occur with either sharp or blunt surfaces. The International Organization for Standardization(ISO) provides a comprehensive categorization of dangers in [18], according on their source. Mechanical dangers occur due to unintentional or unforeseen motions, accidental tool release, motion of rotation, entanglement of hair or clothing, and being trapped inside the robot cell, among other factors.

Electrical dangers include, for example, coming into touch with live components, or being exposed to arc flash. Thermal dangers arise from contact with surfaces that are hot or exposure to excessive atmospheres necessary for industrial processes. Noise dangers arise due to impaired equilibrium, confusion, or failure to effectively synchronize activities via communication. Additional prevalent perils include vibration, radiation, perils arising from the utilization of hazardous substances, perils stemming from the perilous surroundings in which the robot operates (e.g., inadvertent touch with a scorching surface while attempting to evade a sharp edge), and a confluence of these elements. The dangers connected with robots are well acknowledged, however, the origins of these dangers can vary depending on the specific robot system in question. Not all risks described are applicable to every robot, and the amount of risk associated with a certain hazardous circumstance varies across different robots.

Regulations established according to standards are inherently unclear and not readily implementable. Developing measures that are tailored to the characteristics of robots and the unique context in which they operate may be an effective approach to assuring safety in limited environments, such as industrial settings. However, this approach is insufficient for guaranteeing safety in human-robot interaction (HRI) in a universal manner. This is a challenge in maintaining safety during human-robot interactions.

IV. CONSEQUENCES OF UNPROTECTED AND INSECURE ROBOTS

The absence of protection, safety, security, and privacy in robots has many adverse effects on companies. The scenarios shown in the preceding section provide a concise overview of the tangible and practical outcomes that arise from neglecting to prioritize security as a significant concern. The reality is that little focus has been placed on prominent security concerns that have previously shown their destructive potential during previous technological advancements, such as the proliferation of business computer systems and the deployment of the internet. Regrettably, in the present period, we see manufacturers of robots seizing the opportunity and hastily releasing their goods to the market without sufficiently prioritizing security.

Furthermore, manufacturers that do not have solid security processes sometimes lack the knowledge to effectively handle vulnerability reports. The majority of them likely lack a well-established protocol to manage reports and provide security updates to clients. Failure to learn from past experiences and neglecting to prioritize security in the development of robots might have detrimental consequences for manufacturers in the near future. In this research, we have selected three theme elements to examine the consequent adverse effects: human injuries and causalities, data privacy concerns and theft, and damage to the company reputation. However, there is a single dimension, which overlaps with all of them:

Human injuries and loss

The consequences of not sufficiently prioritizing security and safety have been evident and catastrophic from the first use of robots in various industrial settings in the 1980s [19]. The most striking consequence of hazardous and uncontrolled robots has been and continues to be the death or serious injury of people. From a commercial perspective, such consequences are particularly difficult to conceal. Therefore, the most costly ones, both in a direct and indirect manner. Once made public, the resulting extensive litigation and penalties are very impossible to remedy. The first instance of a robot causing a human's death, which occurred in Michigan in 1979, serves as an example of this concept [20]. This event marked the beginning of a long history of firms being obligated to pay fines and settle lawsuits when occurrences involving robots escalated to legal proceedings.

The judge acknowledged that much attention had been provided to robot designing to avert a fatality of this kind in William's situation. His family successfully obtained a 10-million-dollar settlement in a lawsuit for his untimely death caused by Unit Handling Systems, the company responsible for designing the robot. The failure to allocate sufficient resources, time, and effort to safeguarding labor against robots has resulted in significant financial losses for corporations. The most recent documented example dates back to 2016, [21] whereby an automotive components supplier was had to pay a fine of 2.5 million dollars. However, fatalities and severe injuries resulting from robots are not limited only to enterprise machines. In the business world, da Vinci surgical robot stands out as one of the equipment that has faced the highest number of litigations. According to a regulatory filing in 2014, Intuitive, the company that manufactures the equipment, disclosed that they were dealing with 3,000 claims related to product responsibility for operations conducted between 2004 and 2013. Furthermore, the company allocated $67 million to resolve an unknown quantity of claims. Additionally, Intuitive has allocated $16 million in the first half of this year to resolve legal claims [22].

Data privacy and theft issues

Highlighting the economic ramifications of neglecting security, it is important to note that corporations also dread the theft or loss of data. When computers hold data, there is always a potential for vulnerability, whether it is via unintentional or intentional means, such as when a hacker or criminal infiltrates the system and unlawfully acquires data. Robots are retaining data that is susceptible to unauthorized access and theft. Moreover, this data might be used to blackmail organizations in return. Recently, concerns over privacy have arisen, particularly around the legal ramifications of user data being leaked or misused by other parties. The number of lawsuits initiated by clients, end users, and manufacturers will increase as awareness of privacy and its significance continues to grow. Furthermore, similar to the early days of the PC age, robots are presenting intricate concerns about security and privacy, which might not have received much attention. If a personal computer is hacked, the possible consequences include data loss and identity theft. However, robots that combine modern technology with mobility capabilities have the potential to do significant physical harm to individuals and property if they are compromised.

Brand image destruction

Brand image is often described as the cognitive representation that arises when a company's name is spoken. The public perception of the corporation is a dynamic psychological perception, which is influenced by several factors such as the company's conditions, performance, media coverage, and declaration. The brand image is a dynamic entity that has the ability to swiftly transition from a positive to negative state, and vice versa, ultimately settling into a neutral position. Both large corporations and small and medium-sized enterprises (SMEs) apply several corporate advertising strategies to boost their reputation and increase their attractiveness as a supplier, employer, client, borrower, and so on. Incidents and issues, such as those detailed in this book, significantly affect the public view of the firms concerned. History demonstrates that any firm embroiled in problems with its robots endeavors to minimize its repercussions in the public domain at almost any expense. When journalists diligently investigate and report on issues that are then conveyed or leaked to the media, it may have a detrimental impact on the reputation of firms, causing unease. Internally, this refers to interactions among personnel, while externally, it pertains to interactions with consumers, investors, and policy makers. This occurrence has been seen in almost every recorded instance inside the corporate sector.

The disclosure of the Kawasaki manufacturing worker's death caused by a robot in 1981 was delayed until December, almost 6 months later, by the LSBH (Labour Standards Bureau of Hyogo) prefecture in Japan. Nonetheless, in 2015, at a time characterized by widespread communication and emphasized openness, Volkswagen's communication department delayed almost 10 days to publicly acknowledge that a robot was responsible for the death of a worker in one of its factories. The international company only responded when the media began asking questions [23]. The repercussions for the business reputation of the company undergoing such a circumstance might be catastrophic on the basis of public relations. Continuing with the aforementioned scenario, shortly after the Volkswagen event came to light, word spread rapidly worldwide of the tragic death of a worker caused by a robot at an automobile manufacturing. The story was featured in prominent news outlets such as the Daily Pakistan, CNN, and the Washington Post. In the next few decades, HBO (an American firm) purposes to introduce the “Asimov’s Law”, which defines the interactions between robots and humans.

V. SAFETY MEASURES AND STANDARDS FOR INDUSTRIAL ROBOTS

The introduction of industrial robots aimed to replace human workers engaged in hazardous, arduous, tedious, repetitive, and unclean occupations. Historically, these hazardous work environments resulted in harm and illness for human employees. Human workers at workplaces may be exposed to many health concerns, including poisonous fumes, excessive heat, radiation, excessive noise, physical injuries, and other similar risks. Robots are extensively used in automated manufacturing systems to carry out a multitude of operations such as assembling, handling, welding, and painting. Robots enhance both safety and production in heavy industries. Nevertheless, as elucidated in the preceding piece, robots may possibly pose a hazard for individuals in close proximity. This section focuses on incidents resulting from the actions of robots in industrial settings and provides a summary of safety precautions recommended by existing regulations. The ANSI (American National Standards Institute) and the ISO are the most significant standardization agencies that address safety in HRI. ISO 10218 is the latest set of levels that specifically address the safety of industrial robots (IA).

The EU has ratified it without making any modifications. The R2009, an American standards handbook, was publicly released in 1999 [24]. It is extensively used in both the United States and internationally, including its translation into Japanese and subsequent usage in Japan. In 2009, it was renewed without any alterations. The most recent edition, ANSI/RIA R15.06-2012, is now in the process of being reviewed by the public and will be released shortly [25]. Industrial robot accidents occur most often when the human operatoris available in the work cells when the robot is in operation. Furthermore, occurrences may arise when programming or servicing the robot. Robots should possess the ability to ensure human safety, even in the event of failure or intentional abuse. Attaining flawless safety records in all possible situations is unattainable for machines that are required to conduct tasks such as cutting, welding, and carrying heavy objects. Hence, a compromise between efficiency and security is needed. An established safety precaution in a robotic worker cell is the integration of physical safety obstacle surrounding the robot. The primary objective of constructing the obstacle is to protect the work cell from human intrusion during the robot's operation. Safeguards may be categorized as either permanent, such as safety fences, or moveable, such as gates and flaps.

Non-physical protections, such as safety mats, scanners, and light curtains, are used in addition to physical safeguards. According to the ANS for safety standards in IA, the most effective approach to mitigate harm is to switch off the robotic system whenever a person enters the robot work cell [26]. A reliability fence often includes one or more gates that are solely used by humans to access the robot work cells. A gate interlock mechanism is included into the system, halting the robot's operation in the event that the gate is opened. The robot operation does not automatically continue upon closure of the gate. According to Zhang et al. [27], the automated operation must be started from a location outside the protected area and may only occur when all relevant safety measures are functioning. Provisions must be made to create a confined area near the robot. Whenever it is impractical to physically protect the robot work area, precautionary steps must be used. The robot must be equipped with either software-defined restrictions or electric-mechanical axis limiting systems to restrict its movements. Software specified restrictions provide geometric form, referred to as a zone, which serves to restrict the movement of the robot inside its inside or prevent it from invading this zone.

The risk to human workers may be further decreased by ensuring the appropriate installation of a robotic system. To decrease the risk of tripping and falling over wires, elevated floor surfaces are constructed to provide coverage. Designated and delineated areas must be created and prominently labeled, including traffic pathways (such as pedestrian walkways, visiting routes, etc.). Provision must be made for a secure and easily accessible route to support services such as water, gas, and electricity, as well as cleaning facilities, service areas, and control systems. Significant emphasis should be placed on the process of recuperation after a malfunction. Power outages or fluctuations must not pose a danger. The reactivation of power should not result in any movement, as specified in [28]. After the robot has been restored, the operation will need to be manually restarted. The initiation and reinitiation of the robot system should be uncomplicated procedures, necessitating the implementation of appropriate safety and protection measures for functionality. The selection of actuating controls' location must be done meticulously to avoid inadvertent action. The status of actuating controls must be clearly stated, such as indicating power on or fault detected. Often, a worker and robot must collaborate.

Hence, it is not always feasible to deactivate the robot. An effective approach is to enhance the robot's capabilities by integrating a force torque sensor and using force-torque control algorithms, as outlined in [29] and [30]. The force-torque sensor measures both the direction and magnitude of the moment and force. This information is employed to control the motion of robots, taking into account its maximum permissible velocity. Furthermore, the robot will activate a reduced velocity mode when a person is detected inside the robot cell, in summation to using safety control via sensors of force-torque. According to ISO 10218, the maximum safe slow velocity for a robot should not exceed 0.25 m·s−1. The efficiency of safety approaches is influenced by factors such as the size, design, and surroundings of the robot that has to be protected. In certain habitat situations or contexts, such as teaching or programming, a safe slow pace may range from 0.1to 0.2 m/s^{-1}.

Express disapproval towards the 0.25 m/s^{-1} restriction, arguing that it is too confining and significantly hampers the robots' capabilities. The speed restriction suggested by the standard does not effectively apply to the various uses and settings in these two instances. Therefore, standards may be too lenient and broad to be readily applicable, or they may need technical proficiency beyond the user's capacity. To further exemplify this challenge and elucidate the aforementioned constraints imposed by software, we use Section 5.12.3 of ISO 10218-1. According to Gleirscher et al. [31], safety-rated software constraints must always be triggered when the robot is powered on and remain active. However, it is possible that an individual who installs a robot may not follow the installation instructions, resulting in the software restrictions not being properly configured.

Despite the presence of established speed limitations, the close proximity of humans to the robot may nevertheless pose a significant risk. Movements that come close to singularities may generate rapid rates of motion along an axis, even when there are restrictions in place. Operators may encounter these high speeds unexpectedly. Avoidance of singularities is recommended wherever feasible. If the robot motion is not in progress, it should be halted and a prior caution should be given before the robot encounters or adjusts for anomaly. Nevertheless, there are instances when the singularities may be managed without inducing any dangerous movement. Several methodologies have been examined in the literature (e.g., in [32]) to equip the work cell of the robot with various sensors (such as camera, area detectors, and proximity sensors) to assist in identifying the presence of a human in the robot's vicinity. For instance, Park, Park, and Manocha [33] conducted research on methodologies that use this data to dynamically adjust a trajectory in order to decrease the likelihood of collision. Furthermore, there are industrial goods that operate on the same idea, like as SafeMove [34].

Notwithstanding these accomplishments, adapting the robot's strategy in real-time continues to be a struggle. Although there are control techniques available for dynamically adjusting trajectories in real-time, the software used for industrial robots lacks flexibility and mostly depends on pre-established trajectories. In order to bestow industrial robots with adaptability, a comprehensive overhaul of the existing software offered by major robotics manufacturers would be necessary. In addition to ISO 10218, as described in [35], ANSI/RIA R15.06-2012 standards [36] will provide explicit instructions for applications of collaborative robot. This partnership will be the first instance of its kind being permitted under the American law since the ANSI/RIA R.1999 had previously forbidden human involvement with robots in 1999. With the robot control technologies and progress of sensors safety, humans have been able to regain their involvement in the process. However, this capability will be optional and only accessible on newly manufactured robots and robot systems.

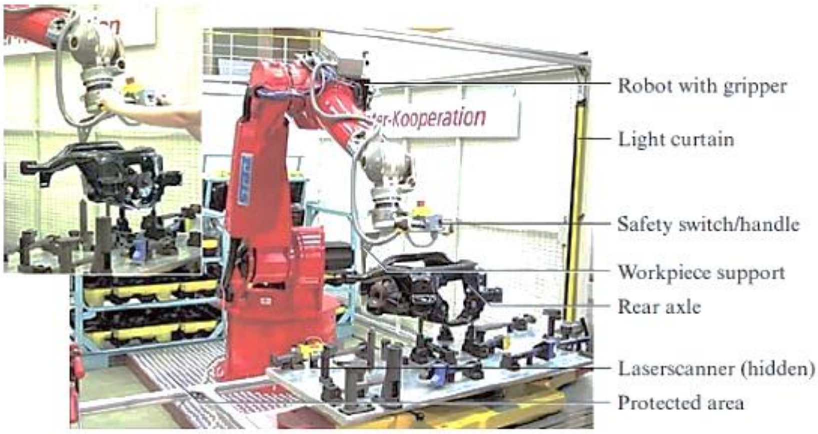

Fig 2.The Collaboration Between Humans and Robots in Order to Carry Out Activities.

Fig 2 depicts an instance of an IA that adheres to the ISO 10218 global standard and incorporates certain safety precautions mentioned earlier. The shown robot functions as a tool to enhance human accuracy, ranging from complete automation to serving as a balancer that is servo-controlled. The illustration depicts a robust gear box being securely held by a robot and delicately stabilized, allowing a worker to accurately insert it into the housing. There are other methods available to safeguard the operators of human inside the work cell during the unloading and loading of work components processes. Throughout this procedure, a rotating table may be used to transfer unprocessed products from the human laborers to the robot, and then return the completed workpieces to the laborers. A rotating table offers the benefit of partitioning the workspace between the robot and the worker, hence minimizing the likelihood of collisions with the robot.

Regardless of the implementation of several safety protocols, accidents may still occur unexpectedly. According to ISO 10218-2, it is mandatory for every robot to be equipped with an independent emergency stop function and a protective stop function [37]. The ideal placement would be at the closest possible distance, while still ensuring safety, to allow the operator to quickly and easily reach it without any obstacles. When a collision occurs, the robot should execute a procedure that is safe and stay motionless until manually reactivated. By adopting this approach, the extent of the harm it inflicts will be reduced to a minimum. Nevertheless, it is not advisable to have the robot promptly start movement in the opposite way, distancing itself from the individual that had an unintended encounter. Under such circumstances, the robot has the potential to crash with an unsuspecting somebody in close proximity who was not anticipating an abrupt change in the robot's path of movement. One of the several issues that robotics must address to maintain safety in dynamic settings populated by people is determining appropriate reaction behavior when the robot comes into touch with humans. A tactile sensor of two-dimensionalis capable of detecting pressures and their distribution in two dimensions.

Within a standard robot enclosure protected by light curtains, the robot operates at a consistent pace to manipulate gear boxes in a completely automated manner. When a person approaches the light curtain, the robot switches to a slower pace. The worker firmly holds the safety switch, so initiating the activation of the force-torque sensor. The human worker smoothly maneuvers the robot using its handle [38].Contact sensing plays a crucial role in providing immediate and essential input for control, whether it is via intentional or unintentional contacts with the surroundings. It may be used as a synthetic skin on a robot and employed to halt the robot's actions in a manner that prioritizes human safety [39]. The precise positioning of tactile sensors is crucial. According to Haddadin and Croft [40], it is important to place a touch sensors throughout the robot`s primary segment does not provide additional data compared to using a torque/force sensor located at the joint. Equipping the robot's flexible or retractable segments with tactile sensing will enhance its functionality by enabling the detection of any entanglement of a human limb between two retractable components of the robot.

VI. CONCLUSIONS

The safety concerns related to robots may be classified into three primary origins: technical deficiencies, human mistakes, and unfavorable environmental conditions. Gaining a comprehensive understanding of these sources is crucial for improving safety in robot systems. The Systematic Causal Analysis Technique (SCAT) may be used to examine data on robot accidents and their causes, with the aim of identifying the fundamental reasons behind these incidents and enhancing safety protocols.When robots are being used for dangerous tasks, human sensitivity to risks increases again. Robots are prone to shock and push injuries, which can be caused by many variables including electrical, biological, thermal and mechanical hazards Inadequate safety, assurance and privacy in robots can have negative consequences on companies, such as financial loss, unauthorized data, privacy concerns, and loss of company reputation. To effectively manage these consequences, corporate leaders and manufacturers must prioritize safety measures and reduce robot-related accidents

Industrial robots are necessary to protect human safety, even in the event of system failure or deliberate misbehavior of the robot. Current regulations recommend the use of safety measures, including non-physical safeguards such as physical barriers, light scanners and curtains, software-based restrictions on robotic movements and dynamic approaches including use to avoid harm when it is not possible to provide physical protection.This integrates deploying sophisticated platforms and dedicated systems to control risks posed to humans. By integrating force torque sensors with force-torque control techniques, the robotic capabilities could be enhanced and its safe activities can be assured. Continuously adjusting the robot's approach in real-time and implementing suitable response patterns when the robot interacts with people are persistent obstacles that need attention. In order to ensure safety in robot systems, it is necessary to use a thorough strategy that takes into account technical deficiencies, human mistakes, unfavorable environmental conditions, and the particular context in which the robots function. To enhance the safety of HRI, it is crucial to comprehend the main sources of risk and adopt suitable safety measures.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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There are no competing interests.

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