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From Rigid to Hybrid/Soft Robots: Exploration of Ethical and Philosophical Aspects in Shifting from Caged Robots to Human-Robot Teaming

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***Abstract*—This paper delves into the ethical, philosophical, and practical dimensions associated with the transition from caged robots to human-robot teaming (HRT). By exploring the evolving dynamics between humans and robots, this paper examines the ethical challenges, philosophical implications, and practical considerations that arise as collaboration and integration between humans and robots deepen. It emphasises the need for responsible design, implementation, and ethical frameworks to guide the development and deployment of human-robot teams. Particular focus is put into the ethical ramifications of choosing between rigid and soft actuators. The study underscores the significance of employing admittance and impedance control techniques to regulate interaction forces and compliance between humans and robots. By analysing the ethical implications of utilising soft actuators, the paper emphasises the potential advantages, such as enhanced safety and reduced risk of harm during close human-robot collaboration.**

I. Introduction

The rapid advancement of robotics technology has led to increased integration of robots into various aspects of our lives. Traditionally, robots were confined within safety cages or barriers to protect human workers from potential hazards [1]. These caged robots were primarily used in manufacturing and industrial settings, performing repetitive tasks with precision and strength. However, recent developments in robotics have paved the way for a gradual paradigm shift from isolated robots, first to human-robot interaction (HRI) [2], to human-robot collaboration (HRC) and lastly human-robot teaming (HRT).

Fig. 1 visualises the different stages of collaboration between robots and humans. The initial stage, caged robots, involves no collaboration and requires no intrinsic safety of the robot. Next, HRI is defined by the exchange of commands from the human operator to the robot. In addition to the exchange of commands, HRC includes the exchange of workspace, while physical HRC (pHRC) involves exchanging forces. Intrinsic safety of the robot becomes crucial in this stage. In the final stage, HRT, the human and robot can exchange solutions, and are considered equal teammates, hence the word teaming.

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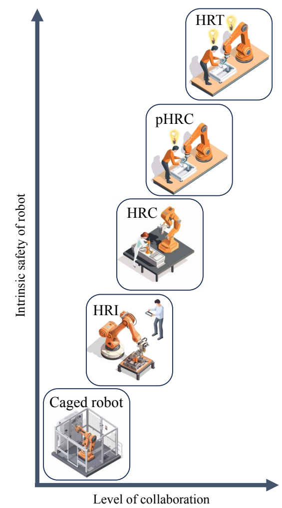

Fig. 1: Human-robot collaboration stages

The motivation behind this shift stems from the desire to enhance efficiency, productivity, and safety in HRI/C/T. By allowing robots to work more closely with humans, there is potential for increased flexibility, adaptability, and a broader range of tasks that can be performed collaboratively. Moreover, the integration of robots in collaborative scenarios can bring about advancements in fields such as healthcare [3], search and rescue operations [4], and autonomous vehicles, where close interaction and teamwork between humans and robots are crucial.

The objectives of the paper can be summarised as follows:

- Explore the ethical considerations arising from the transition from caged robots to HRT.
- Examine the philosophical implications of increased collaboration and integration between humans and robots.
- Identify the practical challenges and opportunities associated with HRT.

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- Investigate the need for responsible design and implementation guidelines in the development of human-robot teams.
- Foster awareness and dialogue regarding the ethical and philosophical dimensions of HRT.
- Contribute to the development of ethical frameworks and guidelines for the integration of robots into human-centric environments.
- Highlight the potential societal impact and benefits of HRT.
- Emphasise the importance of aligning technological progress with ethical considerations and values.

These objectives aim to provide a comprehensive understanding of the ethical, philosophical, and practical aspects involved in the shift from caged robots to HRT, ultimately contributing to the responsible development and integration of human-robot teams. This paper is complemented by two more works published by our research group. In [5], digital twin technology's ethical and philosophical implications are discussed. In [6], the ethical and philosophical aspects of machine learning in human-robot collaboration are considered.

II. Caged Robots: Safety and Isolation

A. Definition and Characteristics of Caged Robots

Caged robots can be defined as industrial robotic systems that are enclosed within safety cages or barriers to ensure the separation and protection of human workers from potential hazards. These cages are typically made of sturdy materials such as steel or polycarbonate, designed to withstand the forces generated by the robot and provide a physical barrier between humans and robots. The cages are equipped with interlocks and sensors that prevent unauthorised access and ensure the robot's operation only when the cage is securely closed. The clear spatial boundary between the human and the robot allows for the use of powerful machinery without too many safety concerns. On the other hand, cages use unnecessary space on the factory floor, leading to inefficient floor planning.

B. Ethical Considerations of Caged Robots

The use of safety cages in caged robots raises ethical considerations regarding the impact on human workers. One important aspect is the potential dehumanisation of the work environment caused by physical separation. Isolating humans from robots within safety cages may create a perception of humans as mere observers or passive supervisors, rather than active participants in the collaborative process. This can have implications for job satisfaction, motivation, and the overall sense of purpose and fulfilment in the workplace.

Furthermore, the reliance on safety cages as the primary safety measure may limit the exploration of alternative approaches to fostering HRI/C/T. While safety cages provide an effective physical barrier, they may inhibit the development of more advanced, cooperative interactions between humans and robots. There is a need to carefully evaluate the balance between safety and collaboration, ensuring that human workers have the opportunity to actively engage with robots while maintaining an acceptable level of risk.

The ethical implications of caged robots also extend to the potential psychological effects on human workers. Isolation from robots and the constant reminder of the need for physical separation might lead to feelings of alienation, detachment, or even a sense of mistrust towards robotic systems. It is essential to consider the psychological well-being of human workers and implement measures that promote a positive human-robot relationship.

III. Human-Robot Interaction/Collaboration: From Isolation to increasing levels of Interaction/Collaboration

A. Advancements in Human-Robot Interaction/Collaboration

HRI/C has witnessed significant advancements in recent years, enabling a shift from isolated robots to collaborative scenarios [7]. These advancements stem from breakthroughs in sensing technologies, actuation systems, and artificial intelligence algorithms. Sophisticated sensors, such as cameras, depth sensors, and tactile sensors, allow robots to perceive and understand human gestures, facial expressions, and body language. These sensors, coupled with powerful algorithms, enable robots to interpret human intentions and adapt their behavior accordingly.

The development of interactive interfaces has played a crucial role in facilitating natural and intuitive communication between humans and robots. Touchscreens, voice recognition systems, and natural language processing capabilities allow humans to interact with robots using familiar modes of communication. This fosters a more seamless and user-friendly interaction, bridging the gap between humans and robots.

The rise of collaborative robots, or cobots, has been instrumental in transforming HRI/C [8]. Cobots are designed to work safely alongside humans, often without the need for physical barriers or safety cages. Equipped with advanced sensing capabilities, including force and proximity sensors, cobots can detect human presence and respond appropriately to ensure safety. These robots are programmed to cooperate with humans, assisting them in tasks that require precision, strength, or repetitive actions. This collaborative approach offers benefits such as increased efficiency, improved productivity, and enhanced task versatility.

B. Ethical Dimensions of Increased Interaction

The increased interaction between humans and robots raises ethical concerns that must be addressed to ensure responsible and beneficial outcomes. Privacy and data security become significant considerations in collaborative human-robot scenarios. The collection and use of personal data, such as images, voice recordings, and behavioural patterns, requires clear guidelines and safeguards to protect individuals' privacy rights. Another ethical dimension is algorithmic bias and discrimination. Machine learning algorithms used in robots' decision-making processes can inadvertently perpetuate biases present in the data they are trained on, leading to discriminatory outcomes.

Ensuring fairness, transparency, and accountability in the design and implementation of these algorithms is vital to prevent and mitigate such biases.

The preservation of human autonomy and dignity is a critical ethical concern in HRI/C. The balance between human agency and the assistance provided by robots must be carefully maintained. Human workers should retain control over decisions and have the ability to override or modify the actions of robots. Additionally, measures should be in place to prevent the devaluation or dehumanisation of human workers, ensuring their contributions and expertise are respected and recognised. In addition, there is a need to address the potential socioeconomic impacts of increased collaboration between humans and robots. The integration of robots in the workforce may disrupt job markets and necessitate reskilling or retraining for human workers. Ethical considerations must encompass fair employment practices, the prevention of job displacement, and the equitable distribution of benefits resulting from HRT.

IV. From Rigid to Hybrid/Soft Robots: Ethical and Philosophical Implications

A. Rigid And Soft Actuatotors

Conventional robots' rigid joints might render a large interaction force when interacting with the environment. This makes controlling position easier and improves position accuracy. Furthermore, rigid joints can respond quickly when the desired position changes. However, the excessive interaction force can harm the environment or the robot itself [9]. One of the solutions to this challenge is to use soft joints. These types of joints help limit and control the interaction force. On the other hand, soft joints have low accuracy in position control. In addition, due to the softness of the joints, they do not have the ability to rapidly respond to changes in the desired position. In [10], elastic joints are used in a snake robot. It helps the robot to crawl in different environments. In [11], [12], pneumatic artificial muscles are presented, which were invented to use in rehabilitation applications.

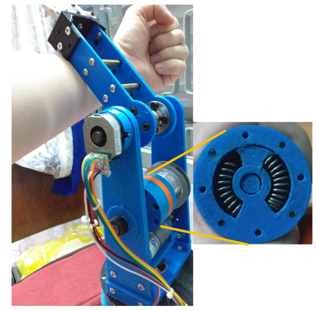

Fig. 2: A soft robotic arm is in a compressed state due to the collision with the environment [9]

Fig. 2 presents a soft robotic arm engaged in a collaborative task with the environment [9]. The arm comprises flexible links with soft actuators that allow free movement. The environment involves an obstacle or object with which the arm interacts during operation. The interaction consists of two phases. First, the soft robotic arm is moving freely in an unconstrained space and approaches the obstacle in a controlled manner. At the beginning of the collision phase, the obstacle prevents the robotic arm from moving in a specific direction. Therefore, when trying to move further in that direction, the robotic arm will deviate from its original trajectory. While the soft robotic arm is in a compressed state due to the collision with the environment, forces are exchanged between the robotic arm and the environment.

B. Admittance and Impedance

Besides softening the interaction force by designing soft joints from a mechanical perspective, imposing desired behaviour on the robot can also be done from the software side [13]. To achieve this, in [14], Hogan presented two concepts, i.e. admittance and impedance. Admittance characteristics imply that the system accepts effort inputs and yields flow outputs, and impedance characteristics imply that the system accepts flow inputs and yields effort outputs. Considering ethics, the application of admittance and impedance control in pHRC has significant implications. Admittance control allows robots to dynamically respond to human actions, fostering cooperation and flexibility in collaborative tasks, thereby ensuring safe and efficient teamwork. However, concerns arise regarding potential human control relinquishment in specific situations. In contrast, impedance control empowers robots to resist external inputs, enhancing safety and stability during interactions. This mechanism prevents accidental collisions and enforces predefined operational limits. Yet, an excessive use of impedance may hinder transparency and robot responsiveness to human intentions, potentially leading to frustration or disengagement in pHRCs.

C. Ethical Implications of Soft Robots

Robots are entering more and more people's daily lives. The interaction between robots and humans is inevitable. Although traditional rigid joint robots have high position control accuracy and fast response ability, they could be dangerous because of the extensive interaction force. Furthermore, when moving fast, rigid-joint robots can cause severe injuries to humans. Therefore, some ethical implications are considered that lead to the emergence and development of soft joints. First, soft robots can reduce the risk of causing injuries to humans when directly interacting with them. Their softness can act as a shock absorber to absorb large interaction forces. The reduced possibility of causing harm or injury to humans when a collision occurs is a crucial benefit, especially in settings involving close proximity between robots and humans.

Furthermore, when entering more and more in daily lives, soft robots can gain humans' trust due to their safety and gentle interaction. This is helpful in areas such as healthcare and domestic applications, where robots will appear as a part of our life. On the other hand, due to the mechanical essence of rigid actuators, it is easy to understand their movements and intentions, while the complex deformations of soft actuators might lead to challenges in predicting their actions. Therefore, to promote HRI/C, transparency in soft robot behaviour needs to be ensured. In addition, soft robots could raise concerns about privacy breaches because of their high flexibility and deformability. The ability to move through tight spaces might be exploited for unauthorised surveillance or data collection. Therefore, ethical guidelines, as well as legitimate regulations, are necessitated to address such issues.

V. Philosophical Perspectives on Human-Robot Relationships

This section explores the philosophical aspects of human-robot relationships, focusing on three key dimensions: moral agency and responsibility, consciousness and personhood in robots, and the implications for human identity and meaning. These philosophical perspectives shed light on the ethical implications and fundamental questions that arise as humans interact and form relationships with robots.

A. Moral Agency and Responsibility

The concept of moral agency relates to the ability to act with intention and make ethical decisions. In the context of human-robot relationships, the question arises as to whether robots can possess moral agency and be held responsible for their actions. Philosophical perspectives vary regarding the moral status of robots. Some argue that robots, being created artifacts, lack the necessary qualities for moral agency and responsibility. Others contend that advanced artificial intelligence systems could potentially exhibit sophisticated decision-making capabilities, leading to the attribution of moral responsibility. This dimension raises profound ethical considerations. If robots were to possess moral agency, how would their actions be evaluated and judged? Should robots be held accountable for any harm caused? The philosophical exploration of moral agency and responsibility in human-robot relationships challenges traditional notions of agency and accountability, calling for a reconsideration of our ethical frameworks.

B. Consciousness and Personhood in Robots

Consciousness and personhood are central philosophical concepts that have long fascinated thinkers. Consciousness refers to subjective awareness, the ability to experience sensations and have subjective experiences. Personhood, on the other hand, encompasses higher-order cognitive capacities, self-awareness, and a sense of identity. The philosophical perspectives on consciousness and personhood in robots diverge. Some argue that robots are unable of experiencing subjective consciousness or possessing personhood. They view robots as sophisticated tools without genuine subjective experiences. However, other perspectives propose that future advances in artificial intelligence and robotics might lead to the emergence of consciousness- or personhood-like qualities in robots. Exploring consciousness and personhood in robots raises fundamental questions about the nature of human consciousness and the criteria for attributing personhood. It challenges our understanding of what it means to be conscious and a person, and how these attributes relate to our moral and ethical considerations in human-robot relationships.

C. Implications for Human Identity and Meaning

Human-robot relationships also raise profound implications for human identity and meaning. As humans interact more intimately with robots, questions arise regarding the impact on human identity and the meaning we derive from our relationships with others. Philosophical perspectives explore whether the inclusion of robots in social contexts could alter the way humans perceive themselves and their relationships with others. The integration of robots into various aspects of human life, including companionship, caregiving, and intimate relationships, challenges our understanding of human-human relationships and the role they play in shaping our identity and providing meaning in life. It raises questions about the potential redefinition of social norms, values, and the boundaries of human relationships. Philosophical perspectives on human identity and meaning in the context of human-robot relationships offer critical insights into the transformative potential of these relationships. They prompt us to reflect on the ethical implications of altering human identity and the importance of preserving human connections and values while engaging with robots.

VI. Ethical Challenges in Human-Robot Teaming

HRT involves the collaboration and integration of humans and robots in shared tasks and decision-making processes [15]. This section explores the ethical challenges that arise in HRT, summarised in Fig. 3. These ethical considerations are crucial for establishing responsible and ethically sound HRT practices.

A. Transparency, Trust, and Accountability

Transparency is a fundamental ethical principle in HRT. Humans need to have a clear understanding of the capabilities, limitations, and intentions of the robots they collaborate with. Lack of transparency can lead to misunderstandings, mistrust, and even accidents. It is essential to provide humans with sufficient information about the capabilities and decision-making processes of robots, enabling them to make informed judgments and appropriately calibrate their expectations. Trust is closely linked to transparency. Humans must be able to trust the reliability and competence of robots in their team.

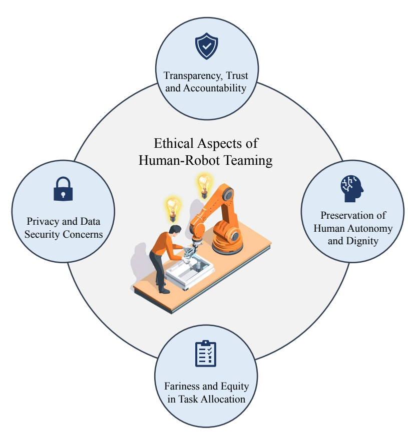

Fig. 3: Ethical aspects of HRT

Trust is built through consistent and predictable behaviour, accurate communication of intentions and limitations, and reliable performance. Establishing trust in HRT is crucial for effective collaboration and for humans to feel comfortable delegating tasks and relying on robots.

Accountability is another vital ethical aspect of HRT. It involves attributing responsibility for actions and their consequences. In cases where robots make decisions or perform actions that have an impact, it is necessary to determine who should be held accountable. Developing frameworks for accountability in HRT is complex but essential for ensuring ethical decision-making and addressing potential issues or harms that may arise.

B. Preservation of Human Autonomy and Dignity

Preserving human autonomy and dignity is a crucial ethical consideration in HRT. Human workers should have the ability to exercise control, make decisions, and retain a sense of agency in their collaborative interactions with robots. The design of human-robot interfaces and control mechanisms should prioritise human autonomy, ensuring that humans can intervene, override, or modify the actions of robots when necessary. Maintaining human dignity involves respecting the rights, values, and well-being of human workers. Robots should not be designed or deployed in a way that undermines or devalues the dignity of human workers. This includes considering the impact of robots on the social and psychological aspects of human work, ensuring that human workers are not marginalised or disempowered in the teaming process.

C. Fairness and Equity in Task Allocation

Fairness and equity in task allocation is an ethical imperative in HRT. The distribution of tasks between humans and robots should be guided by principles of fairness, ensuring that both humans and robots have meaningful and balanced roles. Avoiding the over-reliance on robots or assigning them menial or undesirable tasks is crucial to prevent the exploitation or devaluation of human workers. Transparent and inclusive decision-making processes should be established to determine task allocation. Human workers should have a say in the assignment of tasks and the overall teaming arrangements. This fosters a sense of ownership, empowerment, and engagement, promoting a collaborative environment where human skills and contributions are valued.

D. Privacy and Data Security Concerns

Privacy and data security concerns in HRT are of utmost importance from an ethical perspective. As robots equipped with data collection capabilities become more prevalent, there are legitimate fears of intrusions on individuals' privacy. Transparent communication and informed consent regarding data usage are vital to address these concerns. Organisations must establish clear guidelines, policies, and privacy-enhancing technologies to minimise the collection of personally identifiable information. Data security measures, including secure authentication, encryption techniques, and regular security audits, are crucial to protect sensitive data from unauthorised access and breaches. Adherence to cybersecurity standards and best practices ensures data integrity and fosters a responsible HRT environment. Respecting privacy rights, using data ethically, and maintaining transparency and accountability in data handling practices are essential for an ethically sound implementation of HRT.

VII. Responsible Design, Implementation, and Ethical Frameworks

Ensuring responsible design, implementation, and the establishment of ethical frameworks are essential for promoting the ethical and responsible integration of humans and robots in collaborative settings. This section highlights key aspects related to ethical guidelines for HRT, designing for human-centered collaboration, incorporating ethical considerations in technology development, and the policy and regulatory implications associated with these endeavours.

A. Designing for human-centered collaboration

Ethical guidelines for HRT offer researchers, designers, and practitioners a comprehensive framework to conduct their work in an ethically responsible manner, providing principles and best practices to address the ethical challenges discussed throughout the paper. These guidelines serve as a reference, ensuring transparency, fairness, accountability, and the protection of human rights within HRT contexts. Moreover, designing for human-centred collaboration places humans at the core of the design process, incorporating the needs, capabilities, and preferences of human users into robotic system design. This approach prioritises usability, user experience, and the promotion of human well-being and autonomy, resulting in collaborative environments that optimise productivity, satisfaction, and safety by catering to the unique perspectives and requirements of human users.

B. Incorporating ethical considerations in technology development

Incorporating ethical considerations in technology development involves integrating ethical principles and practices into the entire life cycle of robotic systems. This includes conducting ethical impact assessments during the development and deployment stages, ensuring privacy and security by design, and addressing potential biases or discriminatory outcomes. Ethical considerations should be embedded in the design choices, algorithms, and decision-making processes of robotic systems to promote ethical decision-making and responsible behaviour.

C. Policy implications and regulatory considerations

Policy implications and regulatory considerations are crucial aspects of responsible HRT. As this field continues to evolve, policymakers and regulatory bodies play a vital role in establishing frameworks and guidelines for ensuring ethical and responsible practices. Policymakers need to address issues such as privacy protection, data security, liability, and accountability in HRT. Regulatory frameworks can provide the necessary oversight to prevent unethical or harmful practices, while also promoting innovation, safety, and the public interest.

VIII. Practical Considerations and Future Implications

This section delves into the practical aspects and future ramifications of HRT, focusing on real-world applications and ethical principles. HRT has extensive applications across industries, exemplified by robots collaborating with human workers in manufacturing to enhance productivity and handle dangerous or repetitive tasks. In healthcare, robots aid medical professionals in complex procedures, and during disaster response, human-robot teams conduct search and rescue missions and assess hazardous environments. HRT effectively addresses real-world challenges and enhances human capabilities. Adopting HRT brings numerous societal benefits, such as improved productivity, workplace safety, economic growth, job creation, and reduced risks for human workers. The symbiosis of human creativity and adaptability with the precision and endurance of robots results in better outcomes in healthcare, manufacturing, and agriculture. Moreover, HRT promotes social well-being by supporting the elderly and individuals with disabilities, fostering inclusivity and an improved quality of life. However, responsible integration necessitates prioritising ethical considerations throughout the design, development, and deployment of human-robot systems. Implementing guidelines and regulations ensures transparency, accountability, and fairness while proactively managing potential societal implications, such as job displacement. Striking a balance between technological progress and ethical values allows HRT to positively impact individuals, society, and the advancement of humanity.

IX. Conclusions

In this paper, we have thoroughly examined the ethical, philosophical, and practical dimensions of human-robot interaction (HRI), collaboration (HRC) and teaming (HRT), shedding light on the challenges and considerations within this evolving domain. By exploring the ethical implications of caged robots, philosophical perspectives on human-robot relationships, and the significance of preserving human autonomy and dignity in HRT, we have underscored the importance of striking a balance between safety and efficiency in physical HRC. Additionally, we delved into the ethical challenges, such as transparency, trust, accountability, fairness, and privacy concerns, emphasising the need for responsible design, implementation, and the establishment of ethical frameworks to foster an ethical and responsible HRT environment. It is evident that HRT holds immense potential for transforming industries and addressing societal challenges. However, to harness its benefits while minimising risks, responsible development and integration are paramount. Researchers, designers, policymakers, and stakeholders must collaborate to establish clear ethical guidelines, promote transparency, ensure accountability, safeguard privacy and data security, and prioritise human well-being and autonomy. Striking a harmonious balance between technological progress and ethical considerations will pave the way for a sustainable and beneficial future for HRT. By embracing ethical frameworks and incorporating ethical considerations at all stages, we can foster a mutually beneficial collaboration between humans and robots, where HRT enhances productivity, improves safety, and contributes to the betterment of society.

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