Indonesian Journal of Electrical Engineering and Computer Science
Vol. 39, No. 2, August 2025, pp. 1005~1012
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v39.i2.pp1005-1012

Ethics in human-robot interaction research

Robinson Jimenez Moreno[1], Anny Astrid Espitia Cubillos[2], Javier Eduardo Martinez Baquero[3]
[1]Mechatronic Engineering Program, Faculty of Engineering, Universidad Militar Nueva Granada, Bogotá, Colombia
[2]Industrial Engineering Program, Faculty of Engineering, Universidad Militar Nueva Granada, Bogotá, Colombia
[3]Engineering School, Faculty of Basic Sciences and Engineering, Universidad de los Llanos, Villavicencio, Colombia

Article Info

Article history:

Received Dec 10, 2024
Revised Mar 18, 2025
Accepted Jul 1, 2025

Keywords:

Artificial intelligence
Bioethics
Ethics of technology
Human-machine interaction
Robotics

ABSTRACT

This paper explores the basic ethical and bioethical considerations necessary to mediate interaction with various everyday robots, analyzing several state-of-the-art reports and own research, considering advances in human-robot interaction (HRI) and artificial intelligence (AI). It is important to indicate that the adoption of robotic assistance systems is limited by users' nervousness about the enforcement of ethics, security and privacy of their information, in addition to the regular threats of Internet use, considering that HRI must reason its social and ethical impacts by including specific issues associated with HRI such as autonomy, transparency, deception and policies. In this way, it is relevant both to evaluate how robotic architectures influence people's daily lives and to study how to avoid possible negative impacts. Finally, it is significant to establish the ethical considerations required to enable the development of AI algorithms that help HRI in a natural way.

Corresponding Author:

Anny Astrid Espitia Cubillos
Industrial Engineering Program, Faculty of Engineering, Universidad Militar Nueva Granada
Carrera 11 #101-80, Bogotá, Colombia
Email: anny.espitia@unimilitar.edu.co

1. INTRODUCTION

The increasing presence of robots in various environments implies the need for human-robot interaction (HRI) that is not only successful but also efficient [1]. This interaction process focuses on the study of the various ways in which the relationship between humans and robots is possible through the use of technologies such as artificial intelligence (AI) and in particular machine learning [2]. Given that HRI is in development and a growing boom, in order to design and evaluate robotic systems for use by or with people, it is important to point out in this area some minimum ethical guidelines that must be met. Robotic systems must have the ability to adapt to the actions and behaviors of the user [3] and the environment.

Understanding that the characteristics of a robot can be so broad as to comply with the laws of robotics established by Asimov [4], or that its characteristics can be so specific according to the specific properties of the robot and have limited interaction with the human user. In general, for the successful integration of robots it is necessary to consider the ethical issues of interaction with their environment, which goes hand in hand with the type of development and deployment of robots according to the applications that are oriented. Ethics in robotics is not only relevant for the scientific community, but also for developers, technicians and users [5]. Therefore, the present research seeks to study the basic ethical and bioethical considerations necessary to mediate interaction with everyday robots by analyzing state-of-the-art reports and own research [6]-[10].

Current research on HRI explores more contextualized, reflective, critical, and inclusive design approaches [11]. This article is organized in four parts, starting with the introduction. The second part

explains the methodological steps used, the third part details and discusses the results obtained and, finally, the fourth part presents the conclusions.

2. METHOD

To determine ethical considerations required for the development of AI algorithms that allow HRI in a natural way in specific care tasks, an analysis of the advances in HRI and AI is carried out, considering documented research published in scientific journals or congresses since 2020 and own research, [6]-[10] with results published during the same period. The academic google search using the equation: "ethical + HRI", initially yielded 93 results, filtering by year of publication this figure is reduced to 86 documents that are organized by relevance. By verifying the titles and abstracts of the papers, those presenting a particular focus associated with gender, country, disability and resources are eliminated as they do not focus on the ethical approach to robotic interaction or its application. Ethical considerations applicable to scientific research in HRI are extracted from the selected papers. Figure 1 shows the flowchart of the implemented methodology.

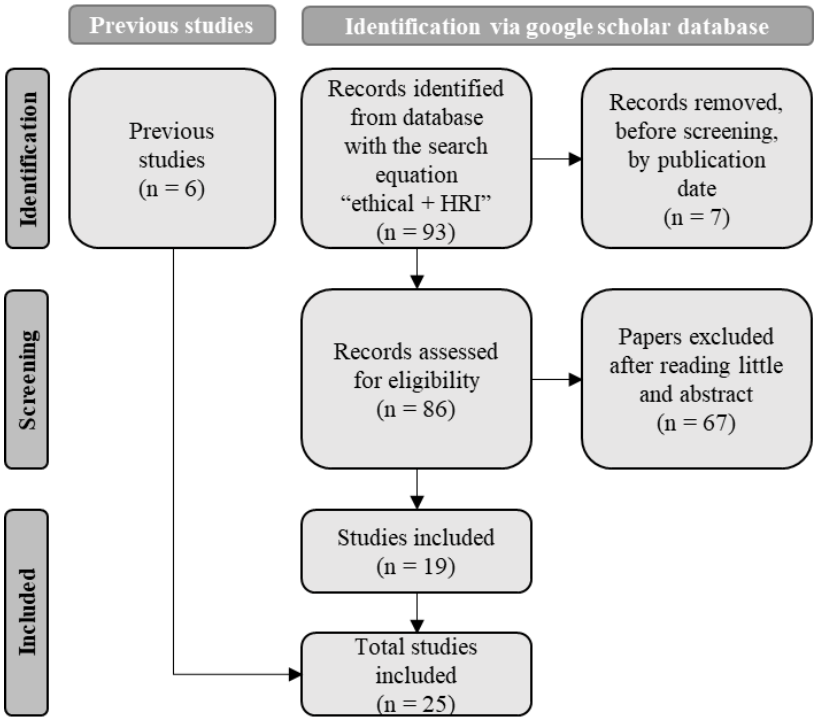

Figure 1. Methodology flowchart (source: adapted from [12])

3. RESULTS AND DISCUSSION

Scientific research in any area has three basic phases, a phase that begins with a conception process where the research project is formulated. Subsequently, there is a phase that involves the execution process, where what was planned is carried out, and finally, a closing phase, where the results obtained are communicated and evidenced as research products. It is in the first phases where it is proposed to keep in mind the ethical and bioethical considerations in scientific research related to HRI, which of course must ensure compliance with scientific integrity from the conception of the research project to the dissemination of the results obtained therefrom. Bearing in mind that the field of HRI is progressively maturing into an autonomous discipline, with its own considerations, practices and eventually research traditions, ethics in this aspect also arises initially from the research team and must ultimately be developed and conceptualized by the robot.

In conception phase, it is suggested to include from the methodological design the five principles of ethical conduct when people are involved, namely: approval of the ethics board, informed consent, data protection and privacy, deception and information [5]. Some of these principles may depend on the type of

interaction, for example, a virtual robot in the testing stage where only the research team is involved may not require informed consent, data protection and privacy, facilitating the structuring and advancement of the project without implications of bioethical impact [6]-[8].

For the execution phase and its subsequent dissemination, in the first instance we explore what is pointed out by [1], where after exchanging results of academic and industrial research focused on fostering an effective and long-lasting human-robot collaboration; it is useful to perceive, in the context of HRI, the perception, discernment, intelligence and decision making process of actors who need to work collaboratively for the achievement of a particular purpose. This requires people to accept and trust robots, which is achieved if they are comfortable with interaction. Robot design must avoid any emotional or physical harm to people and their belongings and, both people and robots need to interpret each other's behavior to act, this is where HRI takes up importance by enabling two-way communication [12], [13]. Then the design must enable robots to detect and respond autonomously to various situations, humans and environments, which is achieved, for example, by integrating AI technologies that ensure respect for ethical principles.

Along the same lines, in [9] regarding the ethics of welfare robotics, three thematic groups are established: welfare, care and justice in the framework of the human ethical dimension to which the levels are linked: individual, practical and socio-political, respectively.

The first theme concerning well-being includes:

- Privacy and data control, considering the right to privacy and control of personal information given the use of robots with tracking capabilities (collection, storage, processing and access to personal data).
- Human autonomy, since too much assistance could cause loss or atrophy of capabilities (muscular, for example), dependence on technology and inadequate delegation of decision making, which in case of failure can lead to frustration and/or stress among others.
- Loss of human contact, since HRI could generate robot emotional dependence or social isolation in user.
- Safety for human physical and psychological integrity, which is related to accidents risk derived from robots sharing space and interacting with humans, where the bioethical principle of non-maleficence applies.
- Dignity as robots could impact it because they cannot care, distress, or reflect supportive emotions.
- Human emotional attachment to robots.
- Reduction of social life, since social interaction with a robot may affect the exercise of human moral faculties (empathy, caring, ...).
- User freedom, understood as the absence of restrictions to the activity itself, is related to machine ethics, which is the way in which a robot weighs conflicting values during process of selecting behaviors to be undertaken.
- Reification, the feeling of users when interacting with robotic devices and the decision to introduce artificial social agents for caring tasks, without intermediate emotions.
- Human moral skills by pseudo-recognition involved in HRI and adoption of social robots in caregiving could reduce opportunities to cultivate moral skills related to human caregiving.
- Recognition, it is not possible for the robot to have a genuinely affectionate relationship and thus deprives humans of recognition.
- Identity, social assistive robotics (SAR) challenge identity by affecting the user's comfort with his or her own image by the appearance of a robot.

In the second theme concerning care:

- Legitimacy of SAR introduction, with respect to tool-task consistency requirements and predilections, is resolved with user-centered design.
- Quality of practice depends on the distribution of tasks between medical staff and SAR.
- In the case of human moral practices, the SAR may end up with the activity of caring for others as a scenario where people's morals are applied.
- Trust inherent in care relationships, as the institution requires assurance of the quality-of-care practice. Safety, responsibility for harm and trust are also associated to adequate information of a robot's jobs and skills.
- Influence on notion of care, changes may be caused in the social values surrounding care, as well as in the social concept of care for the elderly.
- Disruption of roles due to the distribution of tasks between medical personnel and SAR.

In the third theme concerning justice, we find:

- Distributive justice among society.
- SAR technology policy, interests and values behind SAR initiatives.

- Responsibility, mainly by virtue of the technological autonomy of robots, their ability to choose what to do based on previous information processing and with respect to predefined goals, as well as their ability to behave accordingly.
- Social equality, in relation to the possibilities of access to quality treatments
- Robot decision making, to autonomously perform care tasks, requires alignment with human values. This is where machine ethics operates, which aims to endow reasoning robots with ethical principles so that they make decisions by understanding the morals inherent in each environment.
- Ecological sustainability, both local and global.

According to [2] the application of cognitive modeling helps robots to understand both psychology and human behavior, the cognitive model of HRI is an interactive system that can represent the steps associated with providing mental commands to robots, its application coupled with the use of technologies such as AI can help simulate mental processing techniques and human problem solving within robots.

Usability and user experience design principles can be applied to the HRI domain to design robot operations aimed at user comfort and well-being but still require adaptation for the ethical challenges of user privacy and autonomy. In this regard in [10] they propose:

- Principle of feedback with limits for the user about interaction phases, actions, data, conclusions drawn, and possibilities for changing them.
- Minimization of cognitive load focuses on information privacy by breaking information. Users may also be reminded of their previous choices to allow for a new consent.
- Error prevention includes privacy-related information with instruments to notify what information is stored, what sensors are used, what alternatives are selected and how to modify them.
- Consistency increases with the use of design tools that facilitate interaction by allowing robots to identify interaction through sensors.
- Efficiency is adjusted according to the interaction ensuring that the user can select from the available options, which are clearly presented, as well as the conditions and other information.

For [11] the requests for interaction and collaboration between humans and robots at general hospital care are:

- Friendly appearance robot not frightening with human appearance.
- Surface for physical contact, skin-friendly, with some degree of flexibility and capable of warming up to body warmth.
- Interactive human-robot verbal communication capabilities, with reliable recognition of speech and intentions, the voice ringer and the option of longer conversation lengths, plus the robot must display polite etiquette when communicating.
- A crucial issue for healthcare specialists is that human care continues being a responsibility for them, control the possibilities to delegate some rutinal tasks limited beforehand, and robots should have a system with issue warnings in case of delegation of a task violates the duty of care activities. During introduction and capacitation, it is important to indicate clearly that the robot only is a support not a substitute for healthcare professionals. Steps could be shown to acknowledge caregivers to be aware of a robot's autonomous activities at any time.
- Patients want to be part of an interaction friendly, polite and, specially, personalized with a robot; technology should be able to recognize different patients and speak to them using the correct name. In addition, technology should offer all the soport and information adecuatedd for each person according to their particular needs and routines.
- Possibility to finish the communication when the patient decides.

Robot facial expressions and user voice, face, and gesture recognition can communicate different social moods to robots, useful for HRI scenarios [12], [14].

The adoption of assistive robotic systems is limited by user apprehensions relacionated with ethical principies, information security, and privacy, in addition to Internet threats, robotics has haved importants advances in interaction habilities related with tasks as reproduces audio, generates video, permit touch, and gestures recognition, which can recolectes data from user. Therefore, novel and secure interaction techniques are required to protect personal information. The blockchain through a source-alert framework, coupled with a permanent multi-factor authentication procedure, is envisioned as an answer to make systems more secure from conception; consequently, strengthening confidence, appropriateness, and implementation. Among the principal challenges in security, it is critical to design intelligent and autonomos robots that define appropriately the balance between continuous user prompts and system usability based on human data and particular preferences [15].

HRI should consider their social and ethical impacts by including specific issues associated with HRI such as autonomy, transparency, deception, and policies [16], [17]. Following the “Ethical Risk

Assessment of Robots" (ERA), anthropomorphism in SARs is suggested to be a customizable feature adaptable to the user [18]. The ERA concept has been postulated as a tool that inventors and developers could use to assess and mitigate the risks of ethical issues posed by a particular robot usins a systematical way [19].

In [20] it is concluded that verbal anthropomorphization does not affect the perception or efficacy of the studied SAR, which in this case examines a pregnant woman. It is important to evaluate how robotic architectures influence people's daily activities and to study how to avoid possible negative effects, such as colliding with a robot that cleans or generating stress in a user due to a chatbot interaction question-answer.

In general, making an "ethical" decision is a challenge even for people, in this regard robots are being developed that are expected to be able to act ethically, they are programmed by: learning moral examples and using predefined ethical rules [21]-[26]. In this environment the AI use is suitable for this purpose. Previous studies of HRI applications in the real-world real-world have been developed around social robots [27] where participatory design and mixed methods are highlighted as promising strategies and the need to address ethical issues at the beginning of each project. Results that can be extended to other areas of robotics.

In [28] a usability evaluation model is presented, around the use of a human robot interface for assistance to people with reduced mobility. Where the effectiveness, efficiency and user satisfaction play a fundamental role in how to design and evaluate this type of interfaces to cover from its conception and implementation, the functional and ethical aspects that integrate a HRI interface.

Similarly, human robot collaboration (HRC), which today is booming due to the revolutions of industry 4 and 5.0, involves an HRI interface, as presented in [29] in the assistive task in an industrial environment to support robots for moving heavy loads. So that the economic implications of the HRC and implicit HRI interfaces, present advantages and disadvantages from several fronts [30], whose influence will be noticeable in the development and incursion of these technological trends in the medium and long term whose ethical effects should provide for the role of the human being and adaptability both labor, emotional and intellectual in the new context re the industry 5.

Translated with DeepL.com (free version) recently advances in AI under long language models (LLM) as chatGPT [31] expose the reaction of users in relation to its use, which may well be seen as a HRI interaction, since the user interacts directly to obtain an answer that although it may be biased by the language model may also seem ethically compromising in aspects such as racism or under vulnerabilities [32] of the information consulted, as the design of weapons. Finally, Figure 2 summarizes the considerations to be applied in each of the phases of the scientific research process.

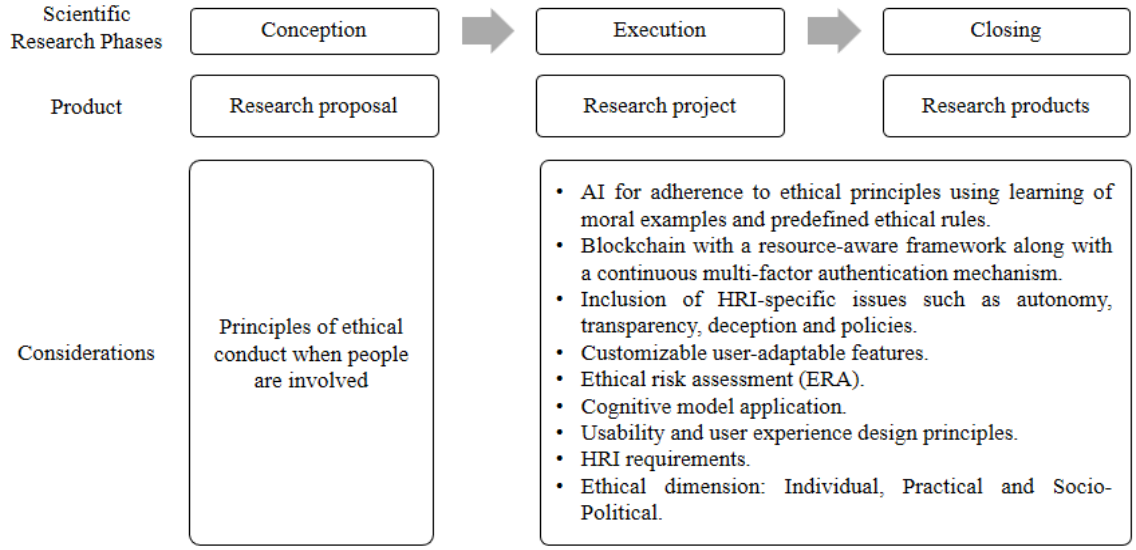

Figure 2. Ethical considerations in the process of scientific research related to HRI

4. CONCLUSION

There are several ethical and bioethical considerations to be taken into account in the different phases of scientific research related to HRI. In the conception phase, the principles of ethical conduct are highlighted when people are involved; in the execution and closure phases, the other proposals that

encompass the ethical dimensions of human life are included. Where it is concluded that the design principles of usability and user experience, nested with the HRI requirements of interaction based on safety, reciprocity and effectiveness, are all algorithmically correlated through AI implementations for action, decision and logic under ethical and moral social principles, all framed in the concept of scientific integrity. Although robotics has advanced rapidly compared to the developments of the last century, current HRI architectures present few causes of physical and mental affectation for people, partly due to the high costs of acquisition and automaton interaction that are so far becoming affordable in basic robotic models. It is concluded that the interaction needs are limited by the capabilities of implementation and behavioral replication of the robot in front of the human, currently due to technological advances in the implementation of AI in portable hardware such as that required by a robot. AI turns out to be a protagonist in the purpose of achieving that robots are designed in such a way that they adequately interpret the behavior of people and act accordingly, within an ethical framework. Therefore, it is concluded that the moral ethical capacity of a robot is still based on the human ability to transfer these concepts to robotic programming algorithms.

As future research, it is proposed to deepen the study of current and prospective developments in HRI in the most natural way possible within a framework that respects the ethical considerations defined here, recognizing the limitations that may arise especially in situations that have not been precisely defined in advance by those responsible for the programming and training of the AI algorithms necessary for its operation, understanding also the variations that derive from cultural differences and including a system that allows for accountability and continuous evaluation of the social and economic impact of HRI developments in the short, medium and long term.

FUNDING INFORMATION

Product derived from the research project titled "Diseño de un modelo de interacción humano-robot utilizando algoritmos de aprendizaje profundo" INV-ING-3971 financed by the vice-rector for research of the Universidad Militar Nueva Granada, year 2024.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Robinson Jiménez-Moreno	✓	✓				✓	✓			✓		✓	✓	✓
Anny Astrid Espitia-Cubillos	✓	✓	✓	✓	✓	✓		✓	✓	✓				
Javier Eduardo Martínez-Baquero	✓	✓								✓	✓			

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] A. Andriella, A. Rossi, S. Rossi, and A. Van Maris, "The road to a successful HRI: AI, trust and ethicS - TRAITS," in *ACM/IEEE International Conference on Human-Robot Interaction*, Mar. 2021, pp. 709–711, doi: 10.1145/3434074.3444872.

[2] M. Farouk, "Studying human robot interaction and its characteristics," *International Journal of Computations, Information and Manufacturing (IJCIM)*, vol. 2, no. 1, May 2022, doi: 10.54489/ijcim.v2i1.73.
[3] B. N. D. Carolis, C. Gena, A. Lieto, S. Rossi, and A. Sciutti, "CaESAR: The fourth workshop on adapted intEraction with SociAl robots," in *ACM International Conference Proceeding Series*, Sep. 2023, pp. 1–4, doi: 10.1145/3605390.3610809.
[4] I. Asimov, "Runaround," *Astounding Science Fiction*, vol. 29, no. 1, pp. 94–103, 1942.
[5] R. Wullenkord and F. Eyssel, "Societal and ethical issues in HRI," *Current Robotics Reports*, vol. 1, no. 3, pp. 85–96, Aug. 2020, doi: 10.1007/s43154-020-00010-9.
[6] J. J. Herrera, R. Jimenez-Moreno, and J. E. M. Baquero, "Virtual environment for assistant mobile robot," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 6, pp. 6174–6184, Dec. 2023, doi: 10.11591/ijece.v13i6.pp6174-6184.
[7] R. Jimenez-Moreno, A. Espitia, and E. Rodríguez, "Virtual assistant robot for physical training exercises supervision," *Iranian Journal of Electrical and Electronic Engineering*, vol. 20, no. 4, p. 3428, 2024.
[8] R. Jiménez Moreno, A. A. Espitia Cubillos, and E. Rodríguez Carmona, "Interactive communication human-robot interface for reduced mobility people assistance," *IAES International Journal of Artificial Intelligence (IJ-AI)*, vol. 14, no. 2, p. 917, Apr. 2025, doi: 10.11591/ijai.v14.i2.pp917-924.
[9] R. Klebbe, K. Klüber, R. Dahms, and L. Onnasch, "Caregivers' perspectives on human–robot collaboration in inpatient elderly care settings," *Machines*, vol. 11, no. 1, p. 34, Dec. 2023, doi: 10.3390/machines11010034.
[10] M. J. Page et al., "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews," The BMJ, vol. 372, 2021, doi: 10.1136/bmj.n71.
[11] N. Fronemann, K. Pollmann, and W. Loh, "Should my robot know what's best for me? Human–robot interaction between user experience and ethical design," *AI and Society*, vol. 37, no. 2, pp. 517–533, Apr. 2022, doi: 10.1007/s00146-021-01210-3.
[12] M. Kyrarini *et al.*, "A survey of robots in healthcare," *Technologies*, vol. 9, no. 1, p. 8, Jan. 2021, doi: 10.3390/technologies9010008.
[13] H. V. Manalu and A. P. Rifai, "Detection of human emotions through facial expressions using hybrid convolutional neural network-recurrent neural network algorithm," *Intelligent Systems with Applications*, vol. 21, p. 200339, Mar. 2024, doi: 10.1016/j.iswa.2024.200339.
[14] J. P. Boada, B. R. Maestre, and C. T. Genís, "The ethical issues of social assistive robotics: A critical literature review," *Technology in Society*, vol. 67, p. 101726, Nov. 2021, doi: 10.1016/j.techsoc.2021.101726.
[15] P. R. Kanna and V. Kumararaja, "Enhancing speech emotion detection with windowed long-term average spectrum and logistic-rectified linear unit," *Engineering Applications of Artificial Intelligence*, vol. 137, p. 109103, Nov. 2024, doi: 10.1016/j.engappai.2024.109103.
[16] J. Marchang and A. Di Nuovo, "Assistive multimodal robotic system (AMRSys): security and privacy issues, challenges, and possible solutions," *Applied Sciences (Switzerland)*, vol. 12, no. 4, p. 2174, Feb. 2022, doi: 10.3390/app12042174.
[17] A. K. Ostrowski *et al.*, "Ethics, equity, and justice in human-robot interaction: a review and future directions," in *RO-MAN 2022 - 31st IEEE International Conference on Robot and Human Interactive Communication: Social, Asocial, and Antisocial Robots*, Aug. 2022, pp. 969–976, doi: 10.1109/RO-MAN53752.2022.9900805.
[18] H. Ma *et al.*, "CFAD: A Chinese dataset for fake audio detection," *Speech Communication*, vol. 164, p. 103122, Oct. 2024, doi: 10.1016/j.specom.2024.103122.
[19] K. Winkle, P. Caleb-Solly, U. Leonards, A. Turton, and P. Bremner, "Assessing and addressing ethical risk from anthropomorphism and deception in socially assistive robots," in *ACM/IEEE International Conference on Human-Robot Interaction*, Mar. 2021, pp. 101–109, doi: 10.1145/3434073.3444666.
[20] K. Winkle, R. B. Jackson, A. Bejarano, and T. Williams, "On the flexibility of robot social identity performance: benefits, ethical risks and open research questions for HRI," *HRI Workshop on Robo-Identity*, 2021.
[21] M. Zhong, M. Fraile, G. Castellano, and K. Winkle, "A case study in designing trustworthy interactions: implications for socially assistive robotics," *Frontiers in Computer Science*, vol. 5, Jun. 2023, doi: 10.3389/fcomp.2023.1152532.
[22] K. Li nd Z. "Ethics of robotics applications," *International Conference on Cognitive based Information Processing and Applications (CIPA 2021)*, vol. 1. pp. 3428, Sep. 2021, Singapore: Springer Singapore, doi: 10.1007/978-981-16-5857-0_41
[23] G. W. Moran, E. J. Margolin, C. N. Wang and G. J. DeCastro "Using gamification to increase resident engagement in surgical training: our experience with a robotic surgery simulation league," *The American Journal of Surgery*, vol. 224, no. 1, pp. 321-322, Jul. 2022, doi: 10.1016/j.amjsurg.2022.01.020
[24] S. Chen, R. Surendran, A. R. Wagner, J. Borenstein, and R. C. Arkin, "Toward ethical robotic behavior in human-robot interaction scenarios. the road to a successful HRI: AI, trust and ethics," *TRAITS Workshop at the Human-Robot Interaction Conference*, 2022.
[25] S. Ljungblad and M. Gamboa, "Critical perspectives in human-robot interaction design," in *Designing Interactions with Robots: Methods and Perspectives*, Chapman and Hall/CRC, 2024, pp. 148–160.
[26] Q. M. Marwan, S. C. Chua and L. C. Kwek, "Comprehensive review on reaching and grasping of objects in robotics", *Robotica*, vol. 39, no. 10, pp. 1849-1882, Feb. 2021, doi: 10.1017/S0263574721000023
[27] J. Rosén, J. Lindblom, and E. Billing, "Reporting of ethical conduct in human-robot interaction research," in *Lecture Notes in Networks and Systems*, vol. 268, Springer International Publishing, 2021, pp. 87–94.
[28] F. Carros, T. Störzinger, A. Wierling, A. Preussner, and P. Tolmie, "Ethical, legal and participatory concerns in the development of human-robot interaction lessons from eight research projects with social robots in real-world scenarios," *I-Com*, vol. 21, no. 2, pp. 299–309, Jul. 2022, doi: 10.1515/icom-2022-0025.
[29] A. Giammarino, J. M. Gandarias, P. Balatti, M. Leonori, M. Lorenzini, and A. Ajoudani, "SUPER-MAN: SUPERnumerary robotic bodies for physical assistance in huMAN–robot conjoined actions," *Mechatronics*, vol. 103, p. 103240, Nov. 2024, doi: 10.1016/j.mechatronics.2024.103240.
[30] M. Dhanda, B. A. Rogers, S. Hall, E. Dekoninck, and V. Dhokia, "Reviewing human-robot collaboration in manufacturing: Opportunities and challenges in the context of industry 5.0," *Robotics and Computer-Integrated Manufacturing*, vol. 93, p. 102937, Jun. 2025, doi: 10.1016/j.rcim.2024.102937.
[31] A. Rapp, C. Di Lodovico, and L. Di Caro, "How do people react to ChatGPT's unpredictable behavior? Anthropomorphism, uncanniness, and fear of AI: A qualitative study on individuals' perceptions and understandings of LLMs' nonsensical hallucinations," *International Journal of Human Computer Studies*, vol. 198, p. 103471, Apr. 2025, doi: 10.1016/j.ijhcs.2025.103471.
[32] M. A. Ferrag *et al.*, "Generative AI in cybersecurity: A comprehensive review of LLM applications and vulnerabilities," *Internet of Things and Cyber-Physical Systems*, vol. 5, pp. 1–46, 2025, doi: 10.1016/j.iotcps.2025.01.001.

BIOGRAPHIES OF AUTHORS

Robinson Jimenez Moreno is an electronic engineer graduated from Universidad Distrital Francisco José de Caldas in 2002. He received a M.Sc. in engineering from Universidad Nacional de Colombia in 2012 and Ph.D. in engineering at Universidad Distrital Francisco José de Caldas in 2018. His current working as associate professor of Universidad Militar Nueva Granada and research focuses on the use of convolutional neural networks for object recognition and image processing for robotic applications such as human-machine interaction. He can be contacted at email: robinson.jimenez@unimilitar.edu.co.

Anny Astrid Espitia Cubillos performed her undergraduate studies in industrial engineering in the Universidad Militar Nueva Granada in 2002 and master in industrial engineering from the Universidad de Los Andes in 2006. She is an associate professor on industrial engineering program at Universidad Militar Nueva Granada, Bogotá, Colombia. She can be contacted at email: anny.espitia@unimilitar.edu.co.

Javier Eduardo Martinez Baquero is an electronic engineer graduated from Universidad de los Llanos in 2002. Posgraduated in electronic instrumentation from Universidad Santo Tomas in 2004, posgraduated in instrumentation and industrial control at Universidad de los Llanos in 2020 and M.Sc. in educative technology and innovative media for education at Universidad Autonoma de Bucaramanga in 2013. His current working as associated professor of Universidad de los Llanos and research focuses on instrumentation, automation, control and renewable energies. He can be contacted at email: jmartinez@unillanos.edu.co.