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5 Human Robot Collaboration on IoT Enabled Environments

Diwakara Vasuman M S[1*], Sridhara Acharya[2], Shalini Suresh[3] & Mahesh V[4]
[1]Research Scholar, Dept. of ICIS, Srinivas University, Mangalore, Karnataka, India & Assistant Professor, Department of Computer Science & Information Technology, JAIN University (Deemed-to-be University), Bengaluru, Karnataka, India.
[2]Professor & Head, Department of ICIS, Srinivas University, Mangaluru, Karnataka, India
[3,4]Associate Professor, Department of Computer Science & Information Technology, JAIN University (Deemed-to-be University), Bengaluru, Karnataka, India.
*Corresponding Author: diwakarbunty@gmail.com

Abstract

The Internet of Things is a network of devices with sensors, software, and network connectivity built in. Through the internet, IoT devices enable us to gather and distribute data with other systems, free from human-to-human or human-to-computer connections. The multidisciplinary academic field of human-robot interaction studies human interaction with robots. It looks at how people and robots might work well and safely together, taking into account both the technical and social aspects of their cooperation. A new generation of smart, connected, and responsive spaces is Human-Robot Collaboration (HRC) using Internet of Things (IoT) technologies. This book chapter looks at how people, robots, and IoT systems work together. Real-time data sharing and smart automation help make communication and cooperation clear. In IoT-enabled settings, robots not only have sensors and actuators but also have distribution, IoT data access-enabled, which lets them make decisions based on context, predict human needs, and change their behaviour dynamically. The technologies and design parts required to enable effective HRC in such contexts, including sensor networks, cloud/edge computing, machine learning, and secure communication protocols, are covered in this chapter. The importance of the human element is highlighted by the talk about safety, transparency, and trust, which are all things that make it easier for people to work together effectively. Emphasized will be instances of actual use in healthcare, smart manufacturing, logistics, and assisted living to illustrate how HRC and IoT together can improve quality of life, lower human workload, and increase efficiency.

Moreover, the chapter examines in depth system interoperability, data privacy, latency, and the ethics of robot autonomy and human dependency. It offers future paths for investigation and design rules for creating user-centric, intelligent, adaptive collaborative robotic systems in ever more complex IoT contexts.

Keywords: Human-Robot Collaboration (HRC), Internet of Things (IoT), Smart Environments, Context-Aware Robotics and Human-Centred Design.

Introduction

Human–robotic collaboration (HRC) is more and more more identified as a cornerstone of present day business and provider systems, wherein human people and robots function collectively inside shared environments (Ajoudani et al., 2018). Unlike conventional robot automation, which frequently isolates robots from people for protection reasons, HRC emphasizes cooperative challenge execution, leveraging the complementary strengths of each parties—human adaptability, problem-solving, and dexterity, along robot precision, endurance, and computational capacity (Villani et al., 2018). The emergence of the Internet of Things (IoT) has substantially extended the operational scope of HRC. IoT refers to a networked environment of bodily gadgets embedded with sensors, actuators, verbal exchange interfaces, and clever software program that permits real-time records trade and self-sustaining coordination (Atzori et al., 2010). When implemented to robot systems, this paradigm offers upward thrust to the Internet of Robotic Things (IoRT), wherein robots end up lively nodes withinside the IoT infrastructure, able to perceiving, processing, and appearing upon dispensed records sources (Simoens et al., 2018).IoT-enabled environments provide remarkable skills for HRC via way of means of presenting non-stop situational awareness, permitting dispensed decision-making, and facilitating scalable, cloud-assisted intelligence. Through cloud robotics, computationally in depth tasks—consisting of real-time item recognition, course planning, and multi-agent coordination—may be offloaded to effective far off servers (Kehoe et al., 2015). In parallel, fog and facet computing architectures carry computational sources towards the bodily environment, lowering latency and enhancing reliability—vital for time-sensitive, protection-vital collaboration tasks (Hu et al., 2015).The integration of HRC and IoT is primary to the conclusion of Industry four. zero and its rising successor, Industry five.zero. In Industry four.zero, the point of interest is on automation, digitization, and interconnectivity, at the same time as Industry five.zero emphasizes human-centric automation, resilience, and sustainability (Nahavandi, 2019). IoT-enabled HRC at once helps those desires via way of means of permitting robots to paintings now no longer simply as tools, however as adaptive, context-conscious teammates.

Background & Key Concepts

Human–robotic collaboration in IoT-enabled environments is an interdisciplinary discipline drawing upon robotics, laptop networks, human–laptop interplay, synthetic intelligence (AI), and cyber–bodily structures. Understanding the foundational standards is important earlier than delving into permitting technology and applications. This segment introduces the number one constructing blocks: collaborative robots (cobots), adaptive collaborative manage, cloud, fog, and aspect robotics architectures, and the Internet of Robotic Things (IoRT).

- **Collaborative Robots (Cobots)**

Collaborative robots, or cobots, are designed to paintings appropriately in near proximity with human operators, with out the want for full-size protection cages or boundaries that represent conventional commercial robots (Bogue, 2018). Unlike traditional automation structures, which might be programmed for repetitive, remoted tasks, cobots can adapt their conduct in reaction to human enter and converting environmental conditions.

- **Key traits of cobots include**
    - **Safety-rated monitored stop** – the cobot halts operation whilst a human enters a delegated protection zone.
    - **Hand guiding** – the cobot may be bodily manipulated through an operator to research trajectories or regulate positioning.
    - **Speed and separation monitoring** – the cobot adjusts pace primarily based totally on its proximity to human workers.
    - **Power and pressure limiting** – torque and pressure are restrained to save you damage for the duration of unintentional contact (ISO/TS 15066:2016).

These competencies are enabled through sensors which include pressure–torque sensors, stereo cameras, LiDAR, and tactile skins, mixed with real-time manage algorithms that make sure compliance and responsiveness (Villani et al., 2018).

- **Adaptive Collaborative Control**

A widespread development in HRC is adaptive collaborative manage, a paradigm wherein robots function as self-reliant but cooperative sellers able to adjusting their movements dynamically primarily based totally on human conduct, environmental cues, and venture demands (Sheridan, 2016). In adaptive structures:

- Perception modules constantly screen human gestures, speech, and physiological cues (e.g., gaze direction, muscle activity).

- Cognitive fashions expect human reason and regulate robotic plans accordingly.
- Learning algorithms refine interplay techniques through the years to enhance fluency and trust.

For example, in an meeting line, an adaptive cobot would possibly stumble on whilst a human is fatigued and autonomously tackle a better percentage of repetitive tasks, or alternatively, yield extra decision-making to the human whilst novel troubles arise (Ajoudani et al., 2018).

Adaptive collaborative manage is mainly essential in IoT-enabled environments, wherein the robotic can leverage disbursed sensing and computation to higher recognize context—integrating facts from wearable devices, clever tools, and environmental sensors.

- **Cloud Robotics**

Cloud robotics integrates robot structures with cloud computing resources, permitting robots to dump computationally highly-priced processes—which include high-decision picture recognition, complicated movement planning, or multi-robotic coordination—to far flung servers (Kehoe et al., 2015).

- **Advantages of cloud robotics include:**
  - **Scalability –** robots can get right of entry to giant garage and processing ability with out nearby hardware limitations.
  - **Shared knowledge –** robots can analyze from every different through importing and retrieving project-particular fashions and experiences.
  - **Continuous improvement –** system getting to know fashions hosted withinside the cloud may be up to date in actual time and deployed fleet-wide.
- **Fog and Edge Robotics**

Fog robotics extends cloud robotics through introducing intermediate computing nodes—called fog nodes—towards the bodily environment, inclusive of on-webweb page servers or gateway devices (Hu et al., 2015). Edge robotics is going even further, processing facts without delay at the robotic or close by embedded devices.

- **The blessings of fog/facet architectures in HRC include:**
  - **Reduced latency –** important for duties that require millisecond-degree response times (e.g., collision avoidance).
  - **Enhanced privacy –** touchy sensor facts may be processed regionally earlier than sending aggregated outcomes to the cloud.

- **Resilience –** robots can hold functioning autonomously in the course of transient cloud outages.

- **The Internet of Robotic Things (IoRT)**

The Internet of Robotic Things (IoRT) is the conceptual fusion of IoT and robotics, wherein robots act now no longer handiest as actuators however additionally as intelligent, networked entities able to sensing, decision-making, and interacting with different IoT devices (Simoens et al., 2018).

- **An IoRT atmosphere generally includes:**
  - **Robotic agents –** cobots, drones, independent vehicles, carrier robots.
  - **IoT sensors/actuators –** environmental sensors, clever cameras, commercial machinery.
  - **Communication infrastructure –** wired/wi-fi networks, 5G, commercial Ethernet.
  - **Integration platforms –** middleware that permits seamless facts change and interoperability.
- **The IoRT paradigm helps multi-area applications:**
  - **Manufacturing –** robots coordinate with clever machines and manufacturing structures for just-in-time operations.
  - **Healthcare** – telepresence robots engage with affected person tracking structures for faraway diagnostics.
  - **Logistics** – independent shipping robots sync with stock monitoring structures for actual-time path optimization.

Enabling Technologies

Human–robotic collaboration (HRC) in IoT-enabled environments is based on a constellation of technology that combine sensing, computation, conversation, and smart decision-making. This phase examines the foundational technology that make such structures possible, together with cloud–fog–side computing paradigms, superior sensing and perception, synthetic intelligence and gadget gaining knowledge of (AI/ML), conversation protocols, and virtual dual technology. Each of those additives performs a essential function in allowing safe, efficient, and adaptive collaboration among people and robots.

- **Cloud, Fog, and Edge Robotics**
  - **Cloud Robotics**

Cloud robotics extends a robotics' abilities with the aid of using offloading computation, storage, and understanding bases to faraway information centres (Kehoe et al., 2015). This structure lets in robots to get right of entry to shared datasets, gadget gaining knowledge of fashions, and real-time analytics without the want for excessive on board processing power.

- **Advantages**
  - **Scalability:** Access to certainly limitless resources.
  - **Learning from Collective Experience:** Robots can add their sensor information and down load fashions educated from international datasets.
  - **Rapid Deployment of New Capabilities**: Software updates and new project scripts may be deployed remotely.
- **Limitations**
  - **Latency Sensitivity:** Tasks requiring millisecond response instances cannot depend completely on cloud resources.
  - **Connectivity Dependency:** Service disruptions can halt operations.

- **Fog Robotics**

Fog robotics introduces an intermediate layer among the cloud and robots, deploying computing nodes toward the bodily surroundings (Bonilla Licea et al., 2021). This reduces latency and allows context-particular processing.

Example: In a collaborative packaging line, a nearby fog server can procedure human movement seize information from wearable sensors and right away modify a cobot`s trajectory with out anticipating cloud confirmation.

- **Edge Robotics**

Edge robotics approaches information immediately at the robotic or on close by IoT devices. This is vital for real-time protection capabilities including impediment avoidance, force-limiting, and emergency stops (Shi et al., 2016). A hybrid structure frequently emerges in practice—real-time protection-essential obligations run at the side, intermediate decision-making takes place at fog nodes, and long-time period gaining knowledge of or analytics arise with inside the cloud.

- **Advanced Sensing and Perception**

HRC in IoT environments relies upon on accurate, multimodal sensing to discover human moves, interpret intent, and understand the encircling surroundings.

- **Vision Systems**
  - **RGB Cameras:** For primary visible recognition.
  - **Depth Cameras (e.g., Intel RealSense, Microsoft Azure Kinect):** To estimate 3-D human pose and surroundings geometry.
  - **Stereo Vision:** Enables intensity estimation from viewpoints.
- **Tactile and Force Sensing**
  - **Force-Torque Sensors:** Measure interplay forces to hold protection.

- **Artificial Skin Sensors:** Provide disbursed tactile feedback (Mittendorfer & Cheng, 2011).

- **Wearable and Ambient Sensors**
  - **IMUs (Inertial Measurement Units):** For monitoring employee movement.
  - **Wearable EEG or EMG:** For brain–laptop or muscle–laptop interfaces.
  - **Environmental IoT Sensors:** Temperature, light, and vibration sensors make a contribution to situational awareness.

- **Machine Learning and Artificial Intelligence**

The foundation of collaborative systems' decision-making is provided by AI and ML. Important strategies consist of:

- **Vision of Computers (CV):** Semantic segmentation, object detection, and human pose estimation are made possible by deep learning models (such as transformers and convolutional neural networks) (Redmon & Farhadi, 2018). For workspace mapping and gesture recognition, CV is essential.
- **Processing Natural Language (NLP):** Human-robot verbal communication is made possible by NLP, which facilitates intuitive task assignment or clarification (Tellex et al., 2020). Context awareness is improved through integration with IoT sensors.
- **Learning by Reinforcement (RL):** According to Kober et al. (2013), RL facilitates adaptive control policies, in which the robot learns the best course of action by making mistakes in either simulated or real-world settings.

System Architecture for IoT-Enabled HRC

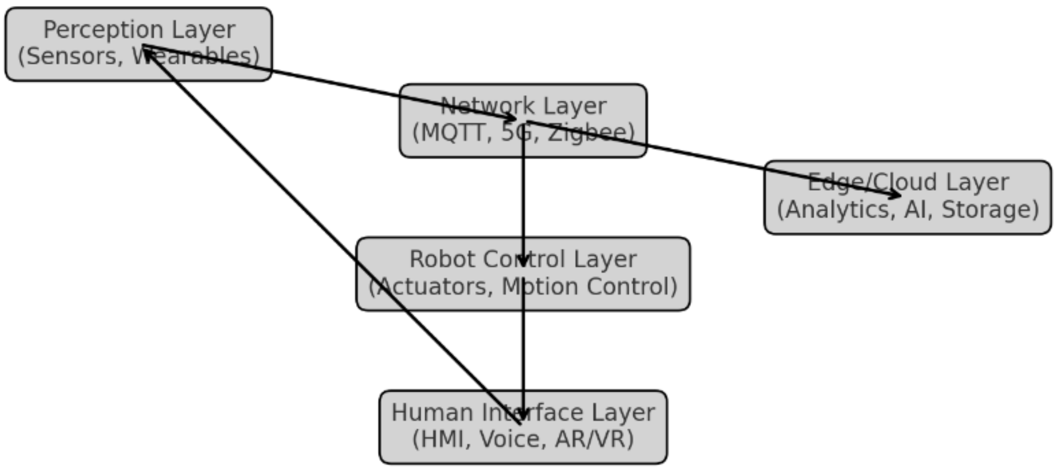

Figure 1: IoT Enabled Human-Robot Collaboration System Environment

An IoT compatible HRC system usually includes the following components:

- Perception layer: Including IoT sensors and environmental data collection transmission.
- Network layer: facilitating communication with standardized protocols.
- Edge / cloud layer: Manage the processing, storage and data analysis in real time.
- Robot control layer: Use cloud information to create action and collaborate with humans.
- Human interface class: including HMI, voice interface, AR / VR system to communicate and respond.

This layered architecture allows the ability to expand, module and react in real time in the context of cooperation (Zhang et al., 2019).

Human Centred Design Considerations

- **Safety and Risk Assessment**

In the shared workspace, security is essential. Instructions for ISO 10218 and ISO / TS 15066 HRC, determining speed, strength and distance (Haddadin & Croft, 2016). IoT sensors contribute by monitoring the closeness and stopping operating when the threshold is violated.

- **Confidence and Transparency**

The transparent systems provide feedback on robots' intentions (through gestures, monitors or voice) to improve human confidence. IoT contributes by allowing the response rounds to hold people with knowledge and control (from Visse et al., 2016).

- **User experience and attendance**

The effective HRC systems are intuitive and adaptable. The interface must be consistent with the capacity and limitations of people. IoT mobile devices, Haptic feedback devices and voice recognition systems improve interaction without overwhelming users.

- **Degrees of Morality and Princess**

Ethical challenges are the result of continuous monitoring, data ownership and employment potential. The design must be given priority, minimizing data and safe communication (calories, 2012).

Applications of HRC in IoT Environments

- **Health and Robotics support**

Robots like Paro and Pepper help the elderly and disabled indoor and hospitals. IoT devices monitor important patients and warn robots for intervention or call for help. These systems reduce the loads of caregivers and support on -site aging (Broadbent et al., 2009).

- **Smart Production**

  Robot cooperates in industrial environment 4.0 to perform repetitive tasks with humans. IoT sensor tracks the conditions, temperature and fatigue of workers. This information allows maintenance of predicting and balancing work volume (Lee et al., 2015).

- **Logistics and Storage**

  Autonomous robots in centers realize cooperation with humans to locate, transport and pack items. IoT systems follow inventory in real time, optimize roads and adjust the behavior of robots according to warehouse traffic and locations of workers (Wurman et al., 2008).

- **Agricultural and environment supervision**

  Drones and robots on the ground monitor plants health, soil conditions and weather conditions through IoT sensors. Human operators guide robots at a distance or directly. Cooperation in stimulating productivity, especially in the contexts related to resources (Bechar and Vigneault, 2016).

Challenges in IoT Enabled Environment

- **Interactive ability and standardization**

  With many types of equipment and protocols, ensuring transparent integration is complex. Open standards and intermediate software platforms are necessary for unified communication (Bandyopadhyay and Sen, 2011).

- **Latency and Reliability**

  Practical cooperation requires minimum latency. It can reduce the delay on the edges, but wireless communication can still be affected in a clogged environment.

- **Data Security and Security**

  IoT devices can be easily attacked. Encryption, access control and abnormal detection is essential to protect the sensitive interactions of robots (Roman et al., 2013).

- **Ethical and Legal Executive Director**

  Lack of complete legal standards for HRC responsibilities. The questions are still responsible in the case of dysfunction, from bias in making decisions and consent of data sharing.

Safety, Security, and Ethical Aspects of Human–Robot Collaboration in IoT-Enabled Environments

- **Physical Safety**

  Collaborative robots, or cobots, are meant to paintings along people without the need of whole bodily separation, however the addition of IoT alters the mathematics of protection:

- **Real-time risk detection:** IoT-sensors (imaginative and prescient cameras, LiDAR) tune human proximity and ship computerized slow-down or prevent commands while a human enters a unique protection zone (Villani et al., 2018).
- **Adaptive pressure and speed manage:** Standards like ISO 10218-2 and ISO/TS 15066 outline protection limits for pressure, pressure, and speed. IoT manage structures dynamically scale cobot parameters primarily based totally on real-time records—like operator fatigue from wearable sensors.
- **Remote protection gadgets:** Supervisors difficulty far off emergency prevent instructions thru IoT interfaces so that it will reply fast withinside the occasion of an dangerous state of affairs being found.

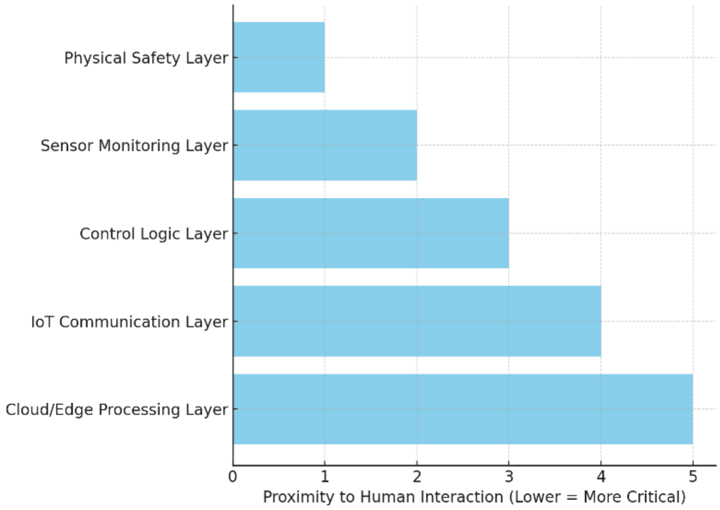

Figure 8.1 (placeholder): Layers of protection controls in IoT-primarily based totally human–robotic collaboration structures

- **Operative Safety**
  - **IoT brings Extra Dangers to Operations**

Latency can reason behind schedule prevent signals, main to accidents. Sensor fusion mistakes—conflicting records from exclusive IoT sensors can bring about risky conclusions.

- **Mitigation Steps**
- Redundant sensing (more than one unbiased detection methods).
- Local side processing for coping with protection-essential operations with out cloud latency**.**

- **Security Considerations**

Security in IoT-more desirable HRC is cybersecurity and bodily security.

- **Cybersecurity Threats**
  - Robots on IoT networks are prone to:
  - Illicit get right of entry to thru compromised IoT endpoints.
  - Wireless verbal exchange among sensors and controllers thru records interception.
  - Malware injection into robotic firmware or manage software.

For instance, in 2017, IO Active researchers uncovered how commercial robots may be hacked to capture manage of movement and pose protection hazards (Quarta et al., 2017).

- **Mitigation**
  - End-to-quit encryption (TLS 1.3) for all IoT communications.
  - Role-primarily based totally get right of entry to manage (RBAC) to robotic manage structures.
  - Routine firmware updates and intrusion detection structures.

- **Physical Security**
  - Unauthorised bodily get right of entry to to IoT-enabled robots can enable:
  - Interfering with actuators or sensors.
  - Malicious IoT gadgets delivered into the network.

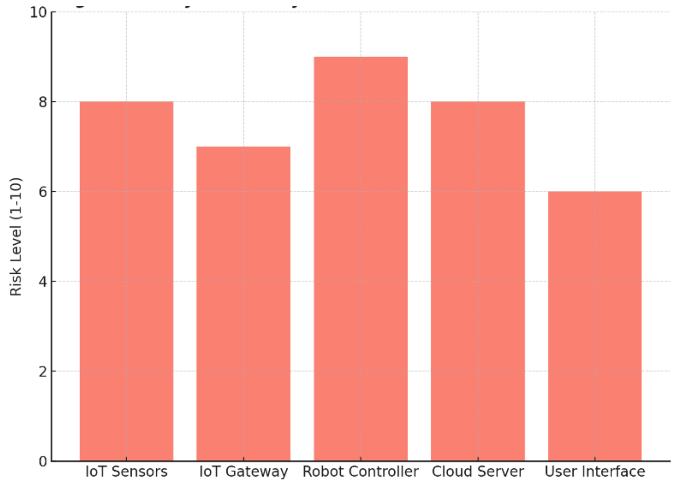

Figure 4: Cybersecurity attack surface map for IoT-enabled robots

- **Mitigation**
  - Safe enclosures for IoT gateways.
  - Tamper-glaring seals.
  - Physical get right of entry to logging structures.

- **Ethical Issues**

The ethical implications of IoT-primarily based totally HRC enlarge past era to human dignity, social values, and justice.

- **Privacy**

As IoT sensors acquire sizable portions of records—the whole thing from biometric fitness records to worker positions—privateness takes middle level withinside the problem.

- **Data minimization:** Gathering records most effective required with the aid of using the task.
- **Transparent records policies:** Informing personnel approximately what records is collected, how it's miles used, and retention periods.

- **Accountability**

Whenever an IoT-enabled collaborative robotic hurts a person, the query of responsibility—whether or not that of the manufacturer, the integrator, the human operator, or the AI developer—is complicated. New EU and OECD criminal frameworks emphasize mutual duty and require specific operational logging to be made to be had for forensic analysis (European Commission, 2021).

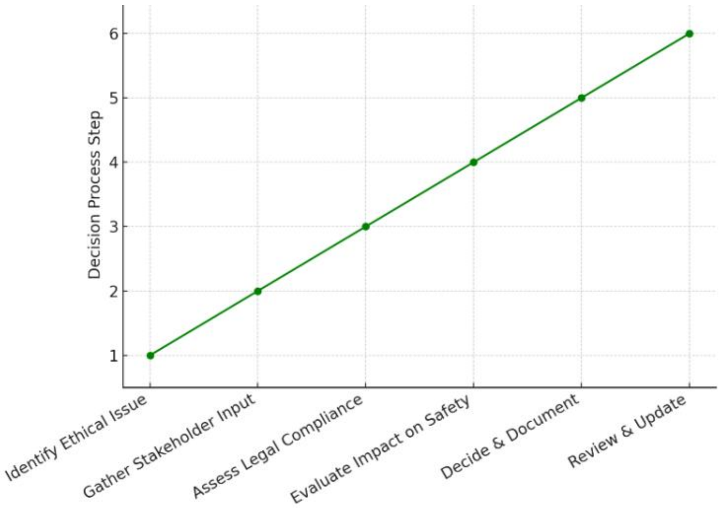

Figure 3: Ethical decision-making framework for HRC

- **Fairness and Bias**

Machine mastering algorithms carried out to robots empowered with the aid of using IoT can by accident introduce biases: In medicine, imbalanced datasets can reason robots to wrongly diagnose signs and symptoms in underrepresented populations. In hiring/schooling robots, discriminatory popularity structures can misrecognize positive demographic groups.

- **Mitigation Encompasses**
  - Representative, various schooling sets.
  - Regular bias checks.
- **Human Autonomy**

Robots ought to support, and now no longer supersede, human judgment. Overdependence on independent processing of IoT facts can erode operator competencies and judgment.

Example: In a warehouse, whilst IoT-robotic structures reschedule duties robotically primarily based totally on sensor readings with out relating to human workers, believe and morale may be lost.

- **Regulatory Frameworks and Norms**

A variety of requirements cope with protection and ethics for IoT-permitting robotics:

- ISO 10218-1/2: Industrial robots - Safety necessities.
- ISO/TS 15066: Safety necessities for collaborative robots.
- IEC 62443: Industrial automation machine cybersecurity.
- IEEE 7000 series: Ethical layout and AI governance guidelines.

Governments also are transferring in the direction of mandating cyber-bodily chance evaluation for IoT-enabled structures as a situation of deployment.

- **Balancing Innovation and Risk**

Implementing IoT-primarily based totally HRC is a compromise: It can also discourage creativity and innovation. Inadequate supervision can bring about unwanted incidents and erosion of public confidence. A "protection-by-layout" and "ethics-by-layout" method ensures that chance control is incorporated on the preliminary layout phase.

Future Trends and Research Direction

- **Cooperation and Personalization**

Future HRC systems will learn options from individual users and adapt over time. Personalized robots will adjust the speech models, levels of motion and support for each user (Fong et al., 2003).

- **Multimodal Interaction**

The combination of voice, gestures, eyes and comments Haptic will create richer and intuitive interfaces. IoT devices will integrate with AR / VR systems to improve the shared awareness.

- **Robotics and Multi -Factor Cooperation**

  Robot groups cooperate with groups of people will be essential to deal with large disasters and industrial tasks. IoT allows decentralized communication and coordination (Brambilla et al., 2013).

- **Digital Twins and Simulation**

  Digital twins of robots and physical environment allows real -time simulation and testing. IoT data provides these models, improving training, maintenance and optimization of performance (Fuller et al., 2020).

Conclusion

Human-Robot Collaboration (HRC) in IoT-enabled environments represents a pivotal shift in how human beings and clever structures paintings collectively to acquire shared goals. The fusion of IoT technology with collaborative robotics has converted static, pre-programmed machines into adaptive, context-conscious companions able to running adequately and efficaciously along people. Through real-time sensing, records sharing, and allotted intelligence, IoT-enabled robots can understand their surroundings, are expecting human intentions, and reply proactively, thereby improving productiveness, safety, and person pleasure throughout various domains. From healthcare and assistive residing to clever manufacturing, logistics, agriculture, and environmental monitoring, the programs of HRC display its capability to enhance nice of life, lessen human workload, and optimize operational outcomes. The integration of sensor networks, edge/cloud computing, and AI-pushed decision-making permits robots to behave with more autonomy even as last conscious of human oversight and collaboration. However, knowing the total capability of IoT-enabled HRC calls for addressing tremendous challenges. Interoperability issues, community latency, records protection vulnerabilities, and moral concerns surrounding autonomy and privateers need to be cautiously managed. Establishing sturdy felony and regulatory frameworks can be important to make certain accountability, safety, and public trust. Looking ahead, improvements in multimodal interaction, personalization, swarm robotics, and virtual dual generation will similarly decorate the adaptability and intelligence of collaborative structures. A human-targeted layout approach—prioritizing safety, transparency, trust, and inclusivity—will stay primary to a success deployment. Ultimately, the destiny of IoT-enabled HRC lies in constructing clever, secure, and moral structures that increase human abilities in preference to update them. By fostering cooperation among human beings, robots, and interconnected devices, we will create clever environments that aren't best greater green and resilient however additionally deeply attuned to human wishes and values. This synergy guarantees to redefine productiveness and innovation with inside the coming decades.

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