Cobotics and XR: Extended Reality Technology as a Core Element of Future Cobot Applications

Cobotics and XR

Current Trends in XR Supporting Cobotics Adoption

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This position paper introduces the topic of two rapidly evolving fields of technology and research – collaborative robotics (cobotics) and extended reality (XR). Both technologies present exponential growth of interest, showing potential to benefit each other and produce novel research within human-robot collaborations. The trends in cobotics and XR research show that novel application or technology-driven, industry-linked research studies trend towards a multidisciplinary reach and strong focus on human-centred studies and novel human-cobot design. Future development of cobotics and XR forecasts to develop into a significant area of research across multiple disciplines. It is anticipated to become a core component of connectivity between humans and cobots and future cobotic applications.

CCS CONCEPTS • **External interfaces for robotics • Mixed/augmented reality • Collaborative interaction • Collaborative and social computing systems and tools**

Additional Keywords and Phrases: Cobots, Extended reality, XR, Human-robot collaboration

1 INTRODUCTION

The ability to increase automation is said to boost Australia's national income by lowering production costs while creating a higher-skilled workforce and more efficient processes. The rapid uptake of automation in the manufacturing industry is changing how products are designed and made and impacting how people work, interact, and collaborate with robots. However, other factors, such as the COVID-19 outbreak, have influenced changes in technologically dependent industries and have made professions realise that their roles can change quickly within the limitations of the new normality of a contactless or restricted world.

As countries progress into Industry 5.0, the focus shifts from technologies that create full automation and smart manufacturing [28] to human-centred processes by leveraging human creativity and collaboration [28,32]. There is an

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increasing need to develop research in human-robot collaboration (HRC) as vital research within the HCI community. For industrial sectors to meet global demands and market needs while increasing efficiencies and upskilling their workforce (Reinhardt et al., 2020), there is a need for flexible systems (Meissner et al., 2020) that are supported by advanced technologies and promote human and robot collaboration. Extended Reality (XR) is the overarching term for one group of emerging technologies showing the potential to become a catalyst in the adoption of cobotics into human workspaces. The different types of XR allow the user to experience both physical and digital environments, with variations of the interplay between real places and digital representations of 3D space – the different XR types are detailed in section 2.2 below.

This paper introduces the prediction that forecasts XR will be a core element of how humans interact with cobotics and will be a significant factor in designing and using future cobot systems. Through XR, we can develop better processes for humans to be creative, interact, and collaborate with robotics.

The rest of this paper is organised as follows. Section 2 discusses the relevant key terms and concepts, Section 3 describes topics within HRC where XR will have an impact, and the final Section 4 provides a summary conclusion and stimulus for further discussion.

2 KEY TERMS AND CONCEPTS

2.1 Cobots

Increasing demand for mass customisation in many industries and the need for flexibility of tasks, robotics has started to adapt and become more human-friendly or "collaborative". Modern cobots are purposefully designed to be safe for humans to operate in close proximity [18,30]. Common traits of cobots include limiting force and payloads and using integrated sensors for collision detection that allow safer operation without barriers in human workspaces. The type and nature of cobots depend on the context of use, task requirements, and combination of safety features. The ability for humans to work with cobots that provide additional strength and repeatability offers alternative avenues for increased efficiencies and productivity while improving human health and safety [30] in often physical, repetitive, and laborious tasks.

The application of cobots into manufacturing workspaces, while offering many opportunities, also comes with challenges regarding the provision of safe work environments for humans and the design of efficient and ergonomically optimised workspaces [36]. HRC research does not rely solely on robotic systems. There is a growing need for a combination of technologies to explore humans' simulation, evaluation, and involvement in the design of collaborative workspaces. Researchers have identified that XR can aid in overcoming some of the challenges of integrating cobots to visualise and evaluate the design of cobotic workspaces [36] while also enabling new ways for workers to interact with cobots [9].

2.2 XR

The term 'extended reality' stylised as 'XR' is widely accepted to cover the spectrum of differing immersive technologies. The letter X is purposely intended to cover future variations of the technology. XR is an umbrella term that includes virtual reality (VR), augmented reality (AR) and mixed reality (MR). XR may also include any technology that sits along a spectrum from 'completely real' to 'completely virtual' [31]. Milgram and Kishino [31] conceptualised the 'Virtuality Spectrum' in 1994, providing a taxonomy for how VR, AR, and hybrid variations such as MR could be categorised. Each of these immersive technologies enables experiences that provide visualisations and sounds in virtual or real environments.

XR tends to use physical movement as an input method [16], with most of the VR and AR commercial market using head-mounted devices [25]. Head motion as a primary input for an XR experience provides other interaction methods to be explored, including handheld controllers and body, eye, or face tracking. Different types of XR use handheld devices such as smartphones or tablets, which require physical movement as the primary input. Allowing users to experience touch in XR via haptic devices is a common addition showing gradual adoption [23,40]. Overall, enabling different method of interaction and engaging with the XR technology extends the visual modality, and experience of digital immersion.

Many commercial XR solutions available can provide immediate benefits to the industry. Off-the-shelf applications can overlay virtual and technical information or communication 3D visuals instead of 2D documentation. Fologram [22] is one such software for augmented reality applications, which are also deemed faster and easier to incorporate into an existing workflow [10]. Previous research examining the adoption challenges of XR found that participants viewed XR technologies as gimmicky or demonstrated concerns about the technology becoming quickly outdated as new versions of the hardware are developed [2]. However, these concerns are outweighed by the potential for XR to allow humans to work with complex information quickly, intuitively, and collaboratively [2]. Several review papers support this view by identifying suitable applications of XR specific to HRC [5,9,35,36]. It is evident that XR played a vital role in connecting and enabling a collaborative relationship between humans and robots by visualising information, programming and controlling robots, simulating workspace processes, training cobotic procedures, and evaluating tasks.

3 KEY AREAS OF FUTURE XR-COBOT APPLICATIONS

This paper argues that XR will become a core component of providing human-robot interactions for future cobot applications. Based on current literature, various approaches can be identified as trends and differentiated to demonstrate future opportunities that XR can provide cobot application and adoption. These areas of XR and cobot research and industry application include (1) HRC safety and workplace acceptance, (2) designing and testing HRC workplace scenarios, (3) reinforcing human awareness of cobot behaviour, (4) cobot prediction of human activity, (5) remote avatars and cobot teleoperation, (6) extension of human senses and digital representation and (7) educational applications and engagement. While not intended to be a definitive list of all XR-cobot research and applications, the topics addressed in the section below indicate areas of recognisable delineated regions of research.

3.1 HRC Safety and Workplace Acceptance

Cobots adhere to strict HRC safety protocols and are rigorously tested in controlled scenarios before integration into industry settings [7]. Testing scenarios to assist humans with dangerous, demanding, and dirty physical jobs are time-consuming and costly [11]. Additionally, there is a need for workplace acceptance and frameworks because introducing cobots can provoke debate and mental distress amongst workers who perceive cobots as a threatening introduction to their work process [33,39]. In these situations, XR can be utilised several ways to help promote safety and acceptance. XR' sandboxes' for testing and interactive applications can be created in limitless configurations to specify human training [1]. Familiarity with cobot and human-cobot interactions can be acquired in XR, where the users can safely explore and become acquainted with cobots [19,20]. Some implementations of VR can provide high levels of immersion to expose workers and prepare them for situations they could experience [29,36,43].

3.2 Designing and Testing HRC Workplace Scenarios

Designing HRC scenarios pose a risk, and testing puts operators under cognitive load and stress [13,33]. A digital representation of a workplace scenario, such as a VR environment, can be used to overcome the pressures, such as the increased cognitive load of learning cobot operations [1,14,24]. Design of human-cobot spaces in VR help with the early stages of planning shared workspaces [36], and later workflow optimisation can be simulated with AR overlaying data in real work environments [29]. Other research examples highlight the advantages of AR and VR for human workers in complex industry settings, including production plant control, safety within production systems, product design, and improved cooperation between humans and machine tools [9].

3.3 Reinforcing Human Awareness of Cobot Behaviour

Many of the examples listed demonstrate how XR can prepare a cobot operator for new experiences within the safety of a VR environment or as AR in a safely controlled workplace [34]. Human interaction with an XR representation of a cobot provides the training operator with familiarity to reinforce their awareness of the cobot [27]. The experience is valuable to understanding cobot actions and reactions to humans in a shared space [12].

3.4 Cobot Prediction of What Humans Do

Capitalising on machine learning (ML), cobot prediction is crucial for future integrations that allow humans and cobots to collaborate on shared tasks, including handover and coordinated actions [5,14,26]. XR provides many options for gathering data, such as human movement in a 3D space [41], gesture recognition [44], gaze detection [8,15], and natural language process for spoken interactions [17]. Data models will initially require a case-by-case evaluation of human activity, and later ML frameworks will use these models for better accuracy of human predictions. Additional advantages include automated feedback to online XR training [20] and evaluating cobot operators in real-time XR environments [1].

3.5 Remote Avatars and Teleoperation

Case examples of remote avatars or teleoperation are used in industries where testing is dangerous or difficult to access, such as nuclear reactors, deep sea, space exploration, factory smelters, and rescue industries [1]. XR can assist in experiencing dangerous or difficult hypothetical scenarios before prototyped testing. Also important in teleoperation is the embodiment concept and the operator's ability to gather feedback from the cobot [1,4]. Multimodal sensors collecting data allow the user to evaluate the outcome of cobot commands [1,38,40]. Recent research examines the remote control of robot arms through MR using head-mounted devices via ROS Reality [35]. Examples of industrial applications include telesurgery, where cobots can support and perform surgical procedures while operators are remotely separated from the patient [1,38].

3.6 Extension of Human Senses and Digital Representation

XR can provide an operator with a visual overlay of data, frequently used as part of AR showing data anchored to the real environment. The data displayed can be customised to the task's requirements [21]. Case examples show location datums, physical properties of materials like mechanical stress or cobot information like action pathways [1]. The advantage of representing data in this way is that it allows an operator to proactively identify risks, predict maintenance needs, and save time or costs [36,42]. MR devices such as the Microsoft HoloLens have been used to demonstrate the sensor data in real time while simulating robotic parts [5]. Sensory data may also be filtered or stylised – for example, noisy environments can be muted or confusing visuals highlighted, limiting operators' cognitive load [3].

3.7 Educational Applications and Engagement

Applications in XR enable cobot teaching through interaction or demonstration using immersive e-learning environments. These applications can be configured to appeal to a wide variety of users or aimed at teaching skills to a varied audience, such as schoolchildren, apprentices, or upskilling experienced workers. Ultimately, these XR approaches allow an operator to experience complex robotic tasks using XR [9,37] safely.

4 CONCLUSION

This paper provides the impetus for discussion around what future XR and cobots may have through exploring the currently emerging and niche area of the two overlapping technology areas. Both disciplines explore the spatial element of computing and robotics, with similarities in hybridised environments, i.e. those spaces that encompass and bridge analogue-digital worlds along a continuum between the virtual and reality [31]. Similarly, both areas are human-driven and therefore well aligned to become a strong niche topic within HRC research with many opportunities for future research.

This paper aimed to provide a general overview of the topics beneficial to the exponentially growing research into emerging technologies and HRC. Specific technologies such as head-mounted devices demonstrate a surge in publication topics that capitalise on the advantages provided by VR or AR. These advantages include visualising data in real environments, e-learning simulations, or multimodal interaction methods. Current literature shows the direction of HRC research focuses on humans as collaborators or decision-makers partnered with intelligent cobots. The research direction in HRC forecasts that future case studies will develop cobots to collaborate on human tasks and simultaneously co-assist and directly interact with humans on shared tasks rather than controlling or reacting to automated processes. The outcomes of these approaches have frequently shown a benefit to humans assisted in tasks by cobots through better efficiency and quality in production outcomes and better safety in the workspace.

Human-centred approaches are well poised to explore HRC through behavioural research, such as workplace technology readiness, human decision-making, and human-in-the-loop design [6]. Alongside this current direction of multidisciplinary research, approaches are novel design methods for creating future HRC systems for various applications across many industries. There is also support for the research trends through drivers linked closely with the industry, such as designing collaborative workspaces, human safety, decision-making, intelligent cobots, and workspace digital twins. Given the number of studies that currently focus on cobotics and XR, the implication shows many gaps and opportunities across several disciplines. As part of these opportunities for future research, HRC tasks and scenarios need further investigation while being agile to adapt to the rapid introduction of new emerging technologies. Additionally, research development outside laboratory and workshop settings should be encouraged to ensure a diversity of applications beyond automotive, aerospace, and similar manufacturing enterprises.

Finally, based on the current literature reviewed, it is suggested that both cobotics and XR are part of a new phase of technologies that design and implement HRC applications around human-centred approaches. The phase places cobotics and XR as a current niche topic but with a strong potential to become a more significant subgenre within HRI, HRC research, and industry. This position paper argues that XR must consider future interaction methods when designing the next generation of cobot systems.

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