

Augmented Reality and Robotics: A Survey and Taxonomy for AR-enhanced Human-Robot Interaction and Robotic Interfaces

Ryo Suzuki

University of Calgary
Calgary, AB, Canada
ryo.suzuki@ucalgary.ca

Adnan Karim

University of Calgary
Calgary, AB, Canada
adnan.karim@ucalgary.ca

Tian Xia

University of Calgary
Calgary, AB, Canada
tian.xia2@ucalgary.ca

Hooman Hedayati
UNC at Chapel Hill
Chapel Hill, NC, U.S.A.
hooman@cs.unc.edu

Nicolai Marquardt
University College London
London, U.K.
n.marquardt@ucl.ac.uk

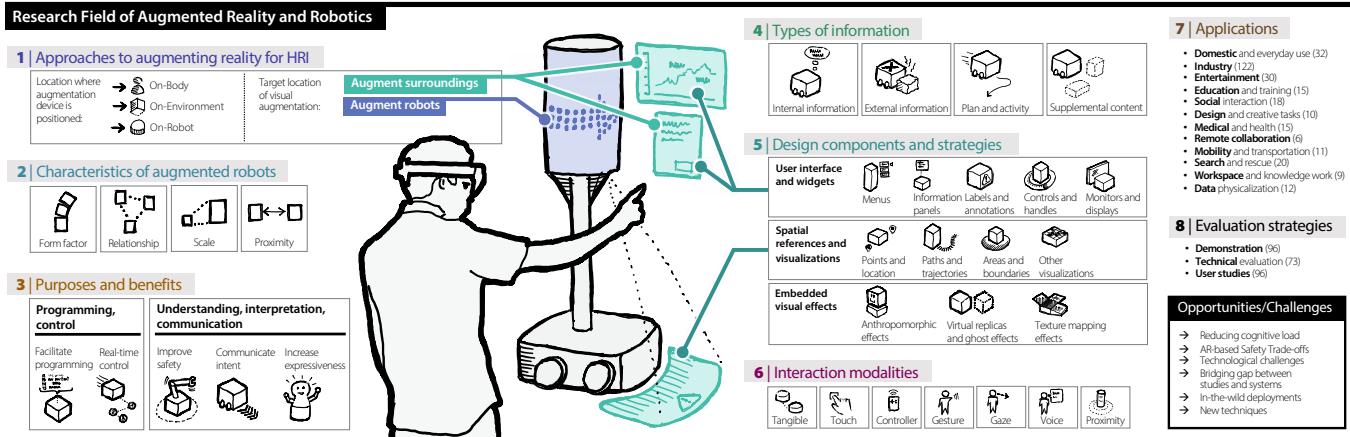


Figure 1: Visual abstract of our survey and taxonomy of augmented reality interfaces used with robotics, summarizing eight key dimensions of the design space. All sketches and illustrations are made by the authors (Nicolai Marquardt for Figure 1 and 3 and Ryo Suzuki for Figure 3-15) and are available under CC-BY 4.0 with the credit of original citation. All materials and an interactive gallery of all cited papers are available at <https://ilab.ucalgary.ca/ar-and-robotics/>

ABSTRACT

This paper contributes to a taxonomy of *augmented reality and robotics* based on a survey of 460 research papers. Augmented and mixed reality (AR/MR) have emerged as a new way to enhance human-robot interaction (HRI) and robotic interfaces (e.g., actuated and shape-changing interfaces). Recently, an increasing number of studies in HCI, HRI, and robotics have demonstrated how AR enables better interactions between people and robots. However, often research remains focused on individual explorations and key design strategies, and research questions are rarely analyzed systematically. In this paper, we synthesize and categorize this research field in the following dimensions: 1) approaches to augmenting reality; 2)

characteristics of robots; 3) purposes and benefits; 4) classification of presented information; 5) design components and strategies for visual augmentation; 6) interaction techniques and modalities; 7) application domains; and 8) evaluation strategies. We formulate key challenges and opportunities to guide and inform future research in AR and robotics.

CCS CONCEPTS

- Human-centered computing → Mixed / augmented reality;
- Computer systems organization → Robotics.

KEYWORDS

survey; augmented reality; mixed reality; robotics; human-robot interaction; actuated tangible interfaces; shape-changing interfaces

ACM Reference Format:

Ryo Suzuki, Adnan Karim, Tian Xia, Hooman Hedayati, and Nicolai Marquardt. 2022. Augmented Reality and Robotics: A Survey and Taxonomy for AR-enhanced Human-Robot Interaction and Robotic Interfaces. In *CHI Conference on Human Factors in Computing Systems (CHI '22)*, April 29-May 5, 2022, New Orleans, LA, USA. ACM, New York, NY, USA, 33 pages. <https://doi.org/10.1145/3491102.3517719>

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than the author(s) must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.

CHI '22, April 29-May 5, 2022, New Orleans, LA, USA

© 2022 Copyright held by the owner/author(s). Publication rights licensed to ACM.

ACM ISBN 978-1-4503-9157-3/22/04...\$15.00

<https://doi.org/10.1145/3491102.3517719>

1 INTRODUCTION

As robots become more ubiquitous, designing the best possible interaction between people and robots is becoming increasingly important. Traditionally, interaction with robots often relies on the robot’s internal physical or visual feedback capabilities, such as robots’ movements [106, 280, 426, 490], gestural motion [81, 186, 321], gaze outputs [22, 28, 202, 307], physical transformation [170], or visual feedback through lights [34, 60, 403, 427] or small displays [129, 172, 446]. However, such modalities have several key limitations. For example, the robot’s form factor cannot be easily modified on demand, thus it is often difficult to provide expressive physical feedback that goes beyond internal capabilities [450]. While visual feedback such as lights or displays can be more flexible, the expression of such visual outputs is still bound to the fixed physical design of the robot. For example, it can be challenging to present expressive information given the fixed size of a small display, where it cannot show the data or information associated with the physical space that is situated outside the screen. Augmented reality (AR) interfaces promise to address these challenges, as AR enables us to design expressive visual feedback without many of the constraints of physical reality. In addition, AR can present visual feedback in one’s line of sight, tightly coupled with the physical interaction space, which reduces the user’s cognitive load when switching the context and attention between the robot and an external display. Recent advances in AR opened up exciting new opportunities for human-robot interaction research, and over the last decades, an increasing number of works have started investigating how AR can be integrated into robotics to augment their inherent visual and physical output capabilities. However, often these research projects are individual explorations, and key design strategies, common practices, and open research questions in AR and robotics research are rarely analyzed systematically, especially from an interaction design perspective. With the recent proliferation of this research field, we see a need to synthesize the existing works to facilitate further advances in both HCI and robotics communities.

In this paper, we review a corpus of 460 papers to synthesize the taxonomy for AR and robotics research. In particular, we synthesized the research field into the following design space dimensions (with a brief visual summary in Figure 1): 1) approaches to augmenting reality for HRI; 2) characteristics of augmented robots; 3) purposes and benefits of the use of AR; 4) classification of presented information; 5) design components and strategies for visual augmentation; 6) interaction techniques and modalities; 7) application domains; and 8) evaluation strategies. Our goal is to provide a common ground and understanding for researchers in the field, which both includes AR-enhanced *human-robot interaction* [151] and *robotic user interfaces* [37, 218] research (such as actuated tangible [349] and shape-changing interfaces [16, 87, 359]). We envision this paper can help researchers situate their work within the large design space and explore novel interfaces for AR-enhanced human-robot interaction (AR-HRI). Furthermore, our taxonomy and detailed design space dimensions (together with the comprehensive index linking to related work) can help readers to more rapidly find practical AR-HRI techniques, which they can then use, iterate and evolve into their own future designs. Finally, we formulate

open research questions, challenges, and opportunities to guide and stimulate the research communities of HCI, HRI, and robotics.

2 SCOPE, CONTRIBUTIONS, AND METHODOLOGY

2.1 Scope and Definitions

The topic covered by this paper is “*robotic systems that utilize AR for interaction*”. In this section, we describe this scope in more detail and clarify what is included and what is not.

2.1.1 Human-Robot Interaction and Robotic Interfaces. “*Robotic systems*” could take different forms—from traditional industrial robots to self-driving cars or actuated user interfaces. In this paper, we do not limit the scope of robots and include any type of robotic or actuated systems that are designed to interact with people. More specifically, our paper also covers *robotic interface* [37, 218] research. Here, *robotic interfaces* refer to interfaces that use robots and/or actuated systems as a medium for human-computer interaction¹. This includes actuated tangible interfaces [349], adaptive environments [154, 399], swarm user interfaces [235], and shape-changing interfaces [16, 87, 359].

2.1.2 AR vs VR. Among HRI and robotic interface research, we specifically focus on AR, but not on VR. In the robotics literature, VR has been used for many different purposes, such as interactive simulation [173, 276, 277] or haptic environments [291, 421, 449]. However, our focus is on visual augmentation *in the real world* to enhance real robots in the physical space, thus we specifically investigate systems that uses AR for robotics.

2.1.3 What is AR. The definition of AR can also vary based on the context [405]. For example, Azuma defines AR as “*systems that have the following three characteristics: 1) combines real and virtual, 2) interactive in real time, 3) registered in 3D*” [32]. Milgram and Kishino also describe this with the reality-virtuality continuum [293]. More broadly, Bimber and Rasker [41] also discuss spatial augmented reality (SAR) as one of the categories in AR. In this paper, we take AR as a broader scope and include any systems that augment physical objects or surroundings environments in the real world, regardless of the technology used.

2.2 Contributions

Augmented reality in the field of robotics has been the scope of other related review papers (e.g., [100, 155, 281, 356]) that our taxonomy expands upon. Most of these earlier papers reviewed key application use cases in the research field. For example, Makhataeva and Varol surveyed example applications of AR for robotics in a 5-year timeframe [281] and Qian et al. reviewed AR applications for *robotic surgery* in particular [356]. From the HRI perspective, Green et al. provide a literature review research for collaborative HRI [155], which focuses in particular on collaboration through the means AR technologies. And more recently, human-robot interaction and VR/MR/AR (VAM-HRI) as also been the topic of workshops [466].

Our taxonomy builds on and extends beyond these earlier reviews. In particular, we provide the following contributions. First,

¹We only cover *internally* actuated systems but do not cover *externally* actuated systems, which actuate passive objects with external force [298, 331, 339, 422].

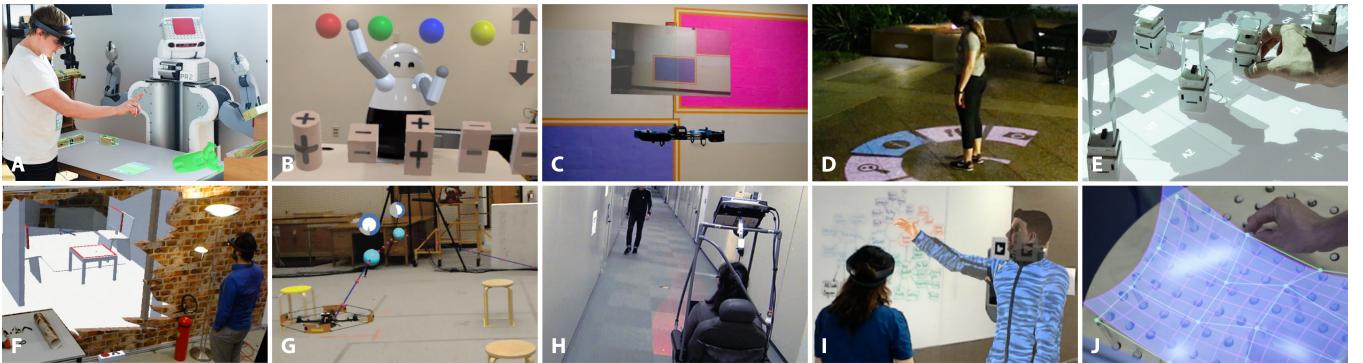


Figure 2: Examples of augmented reality and robotics research: A) collaborative programming [33], B) augmented arms for social robots [158], C) drone teleoperation [171], D) a drone-mounted projector [58], E) projected background for data physicalization [425], F) drone navigation for invisible areas [114], G) trajectory visualization [450], H) motion intent for pedestrian [458], I) a holographic avatar for telepresence robots [198], J) surface augmentation for shape displays [243].

we present a taxonomy with a novel set of *design space dimensions*, providing a holistic view based on the different dimensions unifying the design space, with a focus on *interaction and visual augmentation design perspectives*. Second, our paper also systematically covers a *broader scope of HCI and HRI literature*, including robotic, actuated, and shape-changing user interfaces. This field is increasingly popular in the field of HCI, [16, 87, 349, 359] but not well explored in terms of the combination with AR. By incorporating this research, our paper provides a more comprehensive view to position and design novel AR/MR interactions for robotic systems. Third, we also discuss *open research questions and opportunities* that facilitate further research in this field. We believe that our taxonomy – with the design classifications and their insights, and the articulation of open research questions – will be invaluable tools for providing a common ground and understanding when designing AR/MR interfaces for HRI. This will help researchers identify or explore novel interactions. Finally, we also compiled a large corpus of research literature using our taxonomy as an *interactive website*², which can provide a more content-rich, up-to-date, and extensible literature review. Inspired by similar attempts in personal fabrication [5, 36], data physicalization [1, 192], and material-based shape-changing interactions [6, 353], our website, along with this paper, could provide similar benefits to the broader community of both researchers and practitioners.

2.3 Methodology

2.3.1 Dataset and Inclusion Criteria. To collect a representative set of AR and robotics papers, we conducted a systematic search in the ACM Digital Library, IEEE Xplore, MDPI, Springer, and Elsevier. Our search terms include the combination of “*augmented reality*” AND “*robot*” in the title and/or author keywords since 2000. We also searched for synonyms of each keyword, such as “*mixed reality*”, “*AR*”, “*MR*” for augmented reality and “*robotic*”, “*actuated*”, “*shape-changing*” for robot. This gave us a total of 925 papers after removing duplicates. Then, four authors individually looked at each paper to exclude out-of-scope papers, which, for example, only focus on

AR-based tracking but not on visual augmentation, or were concept or position papers, etc. After this process, we obtained 396 papers in total. To complement this keyword search, we also identified an additional relevant 64 papers by leveraging the authors’ expertise in HCI, HRI, and robotic interfaces. By merging these papers, we finally selected a corpus of 460 papers for our literature review.

While our systematic compilation of this corpus provides an in-depth view into the research space, this set can not be a complete or exhaustive list in this domain. The boundaries and scope of our corpus may not be clear cut, and as with any selection of papers, there were many papers right at the boundaries of our inclusion/exclusion criteria. Nevertheless, our focus was on the development of a taxonomy and this corpus serves as a representative subset of the most relevant papers. We aim to address this inherent limitation of any taxonomy by making our coding and dataset open-source, available for others to iterate and expand upon.

2.3.2 Analysis and Synthesis. The dataset was analyzed through a multi-step process. One of the authors conducted open-coding on a small subset of our sample to identify a first approximation of the dimensions and categories within the design space. Next, all authors reflected upon the initial design space classification to discuss the consistency and comprehensiveness of the categorization methods, where then categories were merged, expanded, and removed. Next, three other co-authors performed systematic coding with individual tagging for categorization of the complete dataset. Finally, we reflected upon the individual tagging to resolve the discrepancies to obtain the final coding results.

In the following sections, we present our results and findings of this classification by using *color-coded text and figures*. We provide a list of *key citations* directly within the figures, with the goal of facilitating lookup of relevant papers within each dimension and all of the corresponding sub-categories. Furthermore, in the appendix of this paper we included several tables with a complete compilation of all citations and count of the papers in our corpus that fall within each of the categories and sub-categories of the design space – which we hope will help researchers to more easily find relevant papers (e.g., finding all papers that use AR for “*improving safety*”

²<https://ilab.ucalgary.ca/ar-and-robotics/>

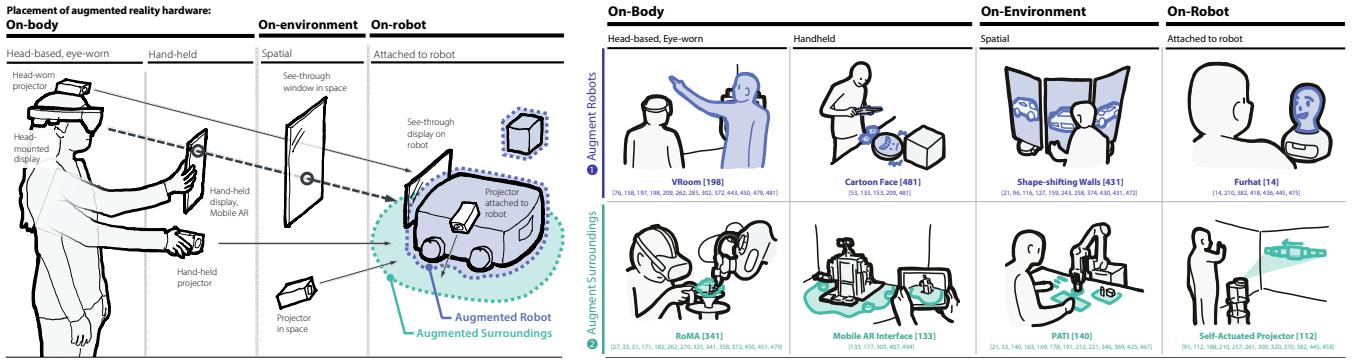


Figure 3: Approaches to augmenting reality in robotics.

with robots, “*augment surroundings*” of robots, or provide visual feedback of “*paths and trajectories*”).

3 APPROACHES TO AUGMENTING REALITY IN ROBOTICS

In this section, we discuss the different approaches to augmenting reality in robotics (Figure 3). To classify how to augment reality, we propose to categorize based on two dimensions: First, we categorize the approaches based on the **placement of the augmented reality hardware** (i.e., where the optical path is overridden with digital information). For our purpose, we adopt and extend Bimber and Raskar’s [41] classification in the context of robotics research. Here, we propose three different locations: 1) *on-body*, 2) *on-environment*, and 3) *on-robot*. Second, we classify based on the **target location of visual augmentation**, i.e., where is augmented. We can categorize this based on 1) *augmenting robots* or 2) *augmenting surroundings*. Given these two dimensions, we can map the existing works into the design space (Figure 3 Right). Walker et al. [450] include augmenting user interface (UI) as another category. Since the research that has been done in this area can be roughly considered augmenting the environment, we decided to not include it as a separate category.

Approach-1. Augment Robots: AR is used to augment robots themselves by overlaying or anchoring additional information on top of the robots (Figure 3 Top).

— **On-Body:** The first category augments robots through on-body AR devices. This can be either 1) head-mounted displays (HMD) [197, 372, 450] or 2) mobile AR interfaces [76, 209]. For example, VRoom [197, 198] augments the telepresence robot’s appearance by overlaying a remote user. Similarly, Young et al. [481] demonstrated adding an animated face onto a Roomba robot to show an expressive emotion on mobile AR devices.

— **On-Environment:** The second category augments robots with devices embedded in the surrounding environment. Technologies often used with this approach include 1) environment-attached projectors [21] or 2) see-through displays [243]. For example, Drone-SAR [96] also shows how we can augment the drone itself with projection mapping. Showing the overlaid information on top of robotic interfaces can also fall into this category. Similarly, shape-shifting

walls [431] or handheld shape-changing interfaces [258, 374] are also directly augmented with the overlaid animation of information.

— **On-Robot:** In the third category, the robots augment their own appearance, which is unique in AR and robotics research, compared to Bimber and Raskar’s taxonomy [41]. For example, Furhat [14] animates a face with a back-projected robot head, so that the robot can augment its own face without an external AR device. The common technologies used are robot-attached projectors [418, 436], which augments itself by using its own body as a screen. Alternatively, robot-attached displays can also fall into this category [445, 475].

Approach-2. Augment Surroundings: Alternatively, AR is also used to augment the surroundings of the robots. Here, the surroundings include 1) surrounding mid-air 3D space, 2) surrounding physical objects, or 3) surrounding physical environments, such as wall, floor, ceiling, etc (Figure 3 Bottom).

— **On-Body:** Similarly, this category augments robots’ surroundings through 1) HMD [372, 450], 2) mobile AR devices [76], or 3) handheld projector [177]. One benefit of HMD or mobile AR devices is an expressive rendering capability enabled by leveraging 3D graphics and spatial scene understanding. For example, Drone Augmented Human Vision [114] uses HMD-based AR to change the appearance of the wall for remote control of drones. RoMA [341] uses HMD for overlaying the interactive 3D models on a robotic 3D printer.

— **On-Environment:** In contrast to HMD or handheld devices, the on-environment approach allows much easier ways to share the AR experiences with co-located users. Augmentation can be done through 1) projection mapping [425] or 2) surface displays [163]. For example, Touch and Toys [163] leverage a large surface display to show additional information in the surroundings of robots. Andersen et al. [21] investigates the use of projection mapping to highlight or augment surrounding objects to communicate the robot’s intentions. While it allows the shared content for multiple people, the drawback of this approach is a fixed location due to the requirements of installed-equipment, which may limit the flexibility and mobility for outdoor scenarios.

— **On-Robot:** In this category, the robots themselves augment the surrounding environments. We identified that the common approach is to utilize the robot-attached projector to augment surrounding physical environments [210, 382]. For example, Kasetani et al. [210]

attach a projector to a mobile robot to make a self-propelled projector for ubiquitous displays. Moreover, DisplayDrone [382] shows a projected image onto the surrounding walls for on-demand displays. The main benefit of this approach is that the user does not require any on-body or environment-instrumented devices, thus it enables mobile, flexible, and deployable experiences for different situations.

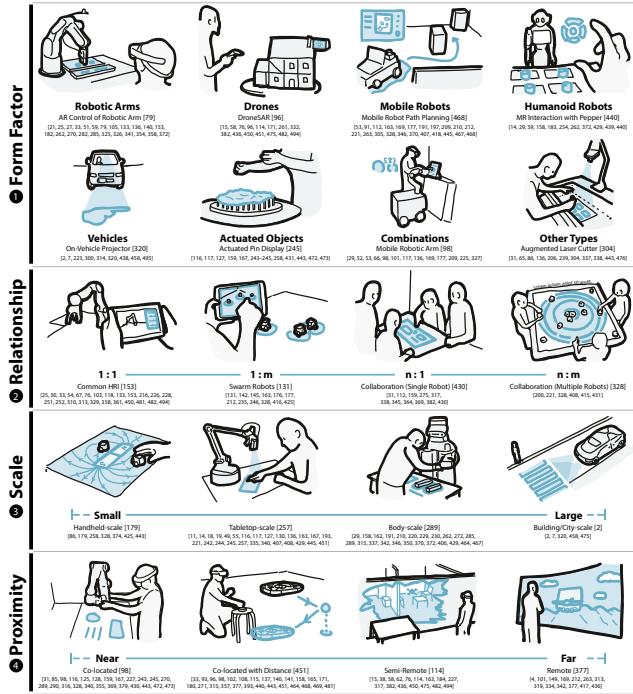


Figure 4: Characteristics of augmented robots.

4 CHARACTERISTICS OF AUGMENTED ROBOTS

Next, we classify research projects based on the characteristics of augmented robots. Possible design space dimensions span 1) the form factor of robots, 2) the relationship between the users and robots, 3) size and scale of the robots, and 4) proximity for interactions ([Figure 4](#)).

Dimension-1. Form Factor: This category includes the types of robots that have been investigated in the literature. The form factor of robots include: robotic arms [341, 354], drones [58, 171], mobile robots [197, 468], humanoid robots [254, 439], vehicles [300, 320], actuated objects [159, 443], the combination of multiple form factors [169], and other types such as fabrication machines [304, 476].

Dimension-2. Relationship: Research also explores different people-to-robot relationships. In the most common case, one person interacts with a single robot (1:1), but the existing research also explores a situation where one person interacts with multiple robots (1:m). AR for swarm robots falls into this category [176, 235,

328, 425]. On the other hand, collaborative robots require multiple people to interact with a single robotic interface (n:1) [430] or a swarm of robots (n:m) [328].

Dimension-3. Scale: Augmented robots are of different sizes, along a spectrum from *small* to *large*: from a small handheld-scale which can be grasped with a single hand [425], tabletop-scale which can fit onto the table [257], and body-scale which is about the same size as human bodies like industrial robotic arms [27, 285]. Large-scale robots are possible, such as vehicles [2, 7, 320] or even building construction robots.

Dimension-4. Proximity: Proximity refers to the distance between the user and robots when interaction happens. Interactions can vary across the dimension of proximity, from *near* to *far*. The proximity can be classified as the spectrum between 1) *co-located* or 2) *remote*. The proximity of the robots can influence whether the robots are directly touchable [227, 316] or situated in distance [96]. It can also affect how to augment reality, based on whether the robots are visible to the user [171] or out-of-sight for remote interaction [114].

5 PURPOSES AND BENEFITS OF VISUAL AUGMENTATION

Visual augmentation has many benefits for effective human-robot interaction. In this section, we categorize the purposes of why visual augmentation is used in robotics research. On a higher level, purposes and benefits can be largely categorized as 1) for programming and control, and 2) for understanding, interpretation, and communications (Figure 5).

Purpose-1. Facilitate Programming: First, the AR interface provides a powerful assistant to facilitate programming robots [33]. One way to facilitate the programming is to *simulate programmed behaviors* [162], which has been explored since early 1990s [32, 219, 294]. For example, GhostAR [51] shows the trajectory of robots to help the user see how the robots will behave. Such visual simulation helps the user to program the robots in industry applications [358] or home automation [263]. Another aspect of programming assistance is to *directly map with the real world*. Robot programming often involves interaction with real-world objects, and going back and forth between physical and virtual worlds is tedious and time-consuming. AR interfaces allow the user to directly indicate objects or locations in the physical world. For example, Gong et al. [150] utilizes projection-based AR to support the programming of grasping tasks.

Purpose-2. Support Real-time Control and Navigation: Similar to the previous category, AR interfaces facilitate the control, navigation, and teleoperation of the robot. In contrast to programming the behaviors, this category focuses on the *real-time* operation of the robot, either remote or co-located. For example, exTouch [209] and PinpointFly [76] allows the user to interactively control robots with the visual feedback on a touch screen. AR interfaces also support showing additional information or parameters related to the navigation and control. For example, a world-in-miniature of the physical world [4] or real-time camera view [171] is used to support remote navigation of drones.



Figure 5: Purposes and benefits of visual augmentation.

Purpose-3. Improve Safety: By leveraging visual augmentation, AR/MR interfaces can improve safety awareness when interacting with robots. For example, Safety Aura Visualization [282] explores spatial color mapping to indicate the safe and dangerous zones. Virtual barriers in AR [68, 182] help the user avoid unexpected collisions with the robots.

Purpose-4. Communicate Intent: AR interfaces can also help to communicate the robot's intention to the user through spatial information. For example, Walker et al. show that the AR representations can better communicate the drone's intent through the experiments using three different designs [450]. Similarly, Rosen et al. reveal that the AR visualization can better present the robotic arm's intent through the spatial trajectory, compared to the traditional interfaces [372]. AR interfaces can be also used to indicate the state of robot manipulation such as indicating warning or completion of the task [21] or communicating intent with passersby or pedestrians for wheelchairs [458] or self-driving cars [320].

Purpose-5. Increase the Expressiveness: Finally, AR can also be used to augment the robot's expression [3]. For example, Groeche et al. [158] uses an AR view to provide virtual arms to a social robot (e.g., Kuri Robot) to enhance the social expressions when communicating with the users. Examples include adding facial expressions [481], overlaying remote users [198, 401], and interactive content [96] onto robots. AR is a helpful medium to increase the expressiveness of shape-changing interfaces [258]. For example, Sublimate [243] or inFORM [127] uses see-through display or projection mapping to provide a virtual surface on a shape display.

6 CLASSIFICATION OF PRESENTED INFORMATION

This section summarizes types of information presented in AR interfaces. The categories we identified include 1) robot's internal information, 2) external information about the environment, 3) plan and activity, and 4) supplemental content (Figure 6).

Information-1. Robot's Internal Information: The first category is the robot's internal information. This can include 1) robot's internal status, 2) robot's software and hardware condition, 3) robot's internal functionality and capability. Examples include the robot's emotional state for social interaction [158, 481], a warning sign when the user's program is wrong [262], the drone's current information such as altitude, flight mode, flight status, and dilution of precision [15, 332], and the robot's reachable region to indicate safe and dangerous zones [282]. Showing the robot's hardware components is also included in this category. For example, showing or highlighting physical parts of the robot for maintenance [285, 302] is also classified as this category.

Information-2. External Information about the Environment: Another category is external information about the environment. This includes 1) sensor data from the internal or external sensors, 2) camera or video feed, 3) information about external objects, 4) depth map or 3D reconstructed scene of the environment. Examples include camera feeds for remote drone operations [171], the world in miniature of the environment [4], sensor stream data of the environment [15], visualization of obstacles [263], a local cost map for search task [305], a 3D reconstructed view of the environment [114, 332], a warning sign projected onto an object that

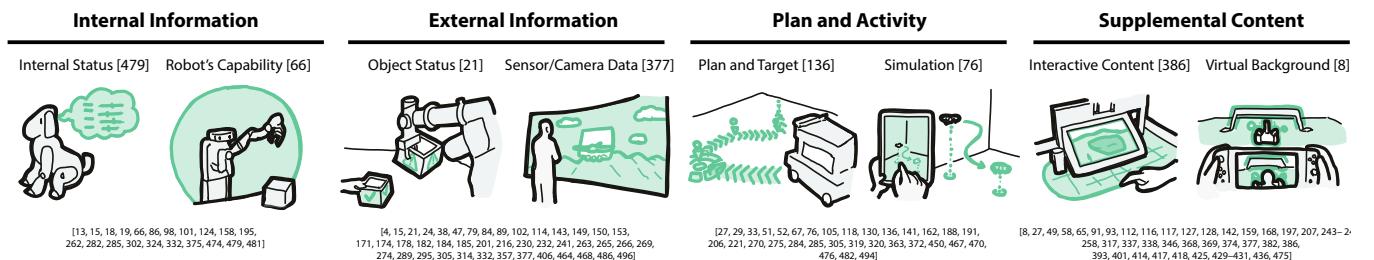


Figure 6: Types of presented information

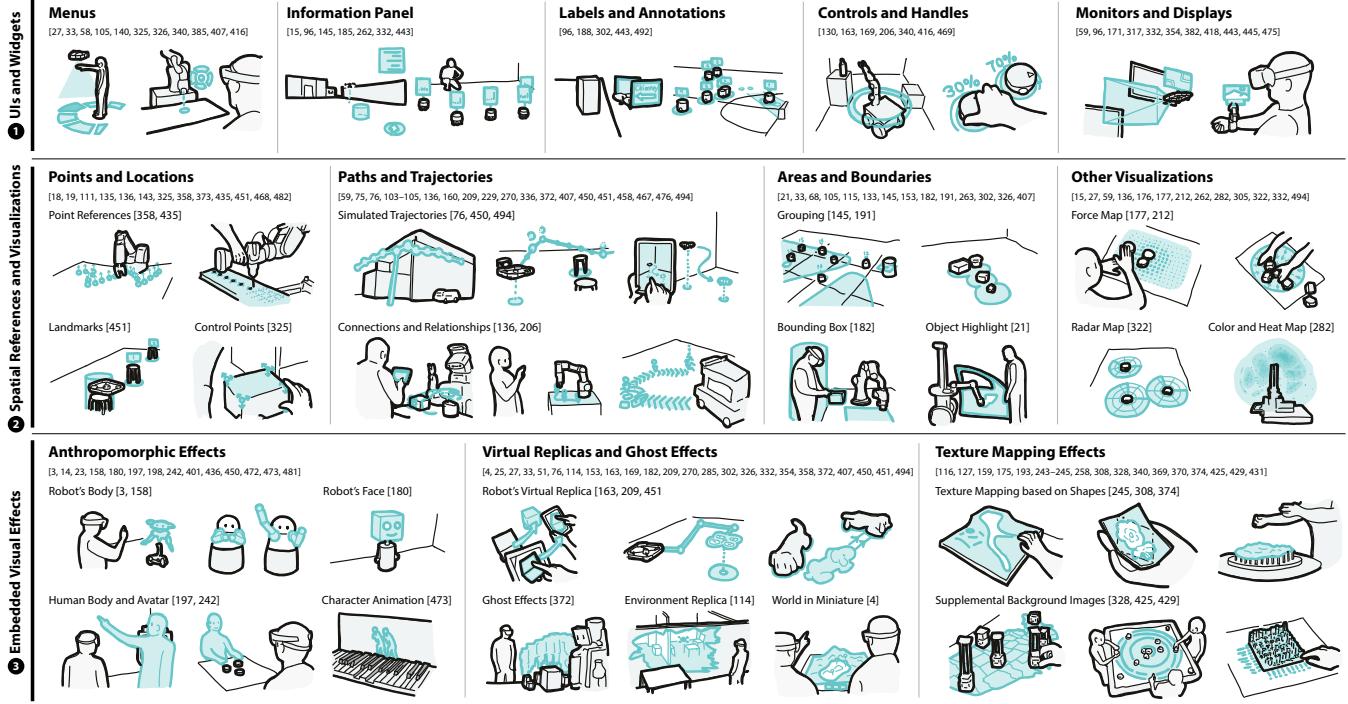


Figure 7: Design components and strategies for visual augmentation

indicates the robot’s intention [21], visual feedback about the localization of the robot [468], and position and label of objects for grasping tasks [153]. Such embedded external information improves the situation awareness and comprehension of the task, especially for real-time control and navigation.

Information-3. Plan and Activity: The previous two categories focus on the *current* information, but plan and activity are related to *future* information about the robot’s behavior. This includes 1) a plan of the robot’s motion and behavior, 2) simulation results of the programmed behavior, 3) visualization of a target and goal, 4) progress of the current task. Examples include the future trajectory of the drone [450], the direction of the mobile robots or vehicles [188, 320], a highlight of the object the robot is about to grasp [33], the location of the robot’s target position [482], and a simulation of the programmed robotic arm’s motion and behavior [372]. This type of information helps the user better understand and expect the robot’s behavior and intention.

Information-4. Supplemental Content: Finally, AR is also used to show supplemental content for expressive interaction, such as showing interactive content on robots or background images for their surroundings. Examples include a holographic remote user for remote collaboration and telepresence [197, 401], a visual scene for games and entertainment [346, 369], an overlaid animation or visual content for shape-changing interfaces [243, 258], showing the menu for available actions [27, 58], and aided color coding or background for dynamic data physicalization [127, 425].

7 DESIGN COMPONENTS AND STRATEGIES FOR VISUAL AUGMENTATION

Different from the previous section that discusses *what* to show in AR, this section focuses on *how* to show AR content. To this end, we classify common design practices across the existing visual augmentation examples. At a higher level, we identified the following design strategies and components: 1) UIs and widgets, 2) spatial references and visualizations, and 3) embedded visual effects (Figure 7).

Design-1. UIs and Widgets: UIs and widgets are a common design practice in AR for robotics to help the user see, understand, and interact with the information related to robots (Figure 7 Top).

— **Menus:** The menu is often used in mixed reality interfaces for human-robot interaction [140, 326, 416]. The menu helps the user to see and select the available options [325]. The user can also control or communicate with robots through a menu and gestural interaction [58].

— **Information Panels:** Information panels show the robot’s internal or external status as floating windows [443] with either textual or visual representations. Textual information can be effective to present precise information such as the current altitude of the drone [15] or the measured length [96]. More complex visual information can also be shown such as a network graph of the current task and program [262].

— **Labels and Annotations:** Labels and annotations are used to show information about the object. Also, they are used to annotate objects [96].

— **Controls and Handles:** Controls and handles are another user interface example. They allow the user to control robots through a virtual handle [169]. Also, AR can show the control value surrounding the robot [340].

— **Monitors and Displays:** Monitor or displays help the user to situate themselves in the remote environment [445]. Camera monitors allow the user to better navigate the drone for inspection or aerial photography tasks [171]. The camera feed can be also combined with the real-time 3D reconstruction [332]. In contrast, monitor or display are also used to display spatially registered content in the surrounding environment [382] or on top of the robot [443].

Design-2. Spatial References and Visualizations: Spatial references and visualizations are a technique used to overlay data spatially. Similar to embedded visualizations [463], this design can directly embed data on top of their corresponding physical referents. The representation can be from a simple graphical element, such as points (0D), paths (1D), or areas (2D/3D), to more complex visualizations like color maps (Figure 7 Middle).

— **Points and Locations:** Points are used to visualize a specific location in AR. These points can be used to highlight a landmark [136], target location [482], or way point [451], which is associated to the geo-spatial information. Additionally, points can be used as a control or anchor point to manipulate virtual objects or boundaries [325].

— **Paths and Trajectories:** Similarly, paths and trajectories are another common approaches to represent spatial references as lines [358, 407, 450]. For example, paths are commonly used to visualize the expected behaviors for real-time or programmed control [75, 76, 494]. By combining the interactive points, the user can modify these paths by adding, editing, or deleting the way points [451].

— **Areas and Boundaries:** Areas and boundaries are used to highlight specific regions of the physical environment. They can visualize a virtual bounding box for safety purposes [68, 182] or highlight a region to show the robot's intent [21, 105]. Alternatively, the areas and boundaries are also visualized as a group of objects or robots [191]. Some research projects also demonstrated the use of interactive sketching for specifying the boundaries in home automation [191, 263].

— **Other Visualizations:** Spatial visualizations can also take more complex and expressive forms. For example, spatial color/heat map visualization can indicate the safe and danger zones in the workspace, based on the robot's reachable areas [282]. Alternatively, a force map visualizes the field of force to provide visual affordance for the robot's control [176, 177, 212].

Design-3. Embedded Visual Effects: Embedded visual effects refer to graphical content directly embedded in the real world. In contrast to spatial visualization, embedded visualization does not need to encode data. Common embedded visual effects are 1) anthropomorphic effects, 2) virtual replica, and 3) texture mapping of physical objects (Figure 7 Bottom).

— **Anthropomorphic Effects:** Anthropomorphic effects are visual augmentations that render human-inspired graphics. Such design can add an interactive effect of 1) a robot's body [3], such as arms [158] and eyes [450], 2) faces and facial expressions [14, 180, 481], 3) a human-avatar [198, 401, 472], or 4) character animation [23, 473],

on top of the robots. For example, it can augment the robot's face by animated facial expression with realistic images [14] or cartoon-like animation [481], which can improve the social expression of the robots [158] and engage more interaction [23, 473]. In addition to augmenting a robot's body, it can also show the image of a real person to facilitate remote communication [197, 401, 436, 472].

— **Virtual Replica and Ghost Effects:** A virtual replica is a 3D rendering of robots, objects, or external environments. By combining with spatial references, a virtual replica is helpful to visualize the simulated behaviors [76, 169, 372, 451, 494]. By rendering multiple virtual replicas, the system can also show the ghost effect with a series of semi-transparent replica [51, 372]. In addition, a replica of external objects or environments is also used to facilitate co-located programming [25, 33] or real-time navigation in the hidden space [114]. Also, a miniaturized replica of the environment (i.e., the world in miniature) helps drone navigation [4].

— **Texture Mapping Effects based on Shape:** Finally, texture mapping overlays interactive content onto physical objects to increase expressiveness. This technique is often used to enhance shape-changing interfaces and displays [127, 175, 308, 374], such as overlaying terrain [244, 245], landscape [116], animated game elements [258, 431], colored texture [308], or NURBS (Non-Uniform Rational Basis Spline) surface effects [243]. Texture effects can also augment the surrounding background of the robot. For example, by overlaying the background texture onto the surrounding walls or surfaces, AR can contextualize the robots with the background of an immersive educational game [369, 370], a visual map [340, 425, 431], or a solar system [328].

8 INTERACTIONS

Dimension-1. Level of Interactivity: In this section, we survey the interactions in AR and robotics research. The first dimension is level of interactivity (Figure 8).

— **No Interaction (Only Output):** In this category, the system uses AR solely for visual output and disregards user input [158, 261, 332, 372, 382, 418, 436, 450, 481]. Examples include visualization of the robot's motion or capability [282, 372, 450], but these systems often focus on visual outputs, independent of the user's action.

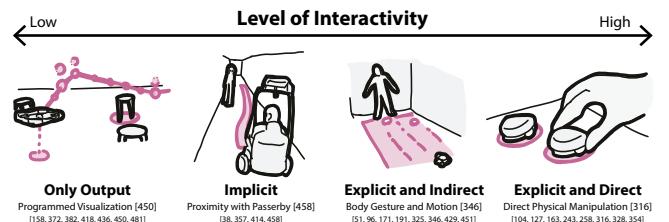


Figure 8: Level of interactivity

— **Implicit Interaction:** Implicit interaction takes the user's implicit motion as input, such as the user's position or proximity to the robot [458]. Sometimes, the user may not necessarily realize the association between their actions and effects, but the robots respond

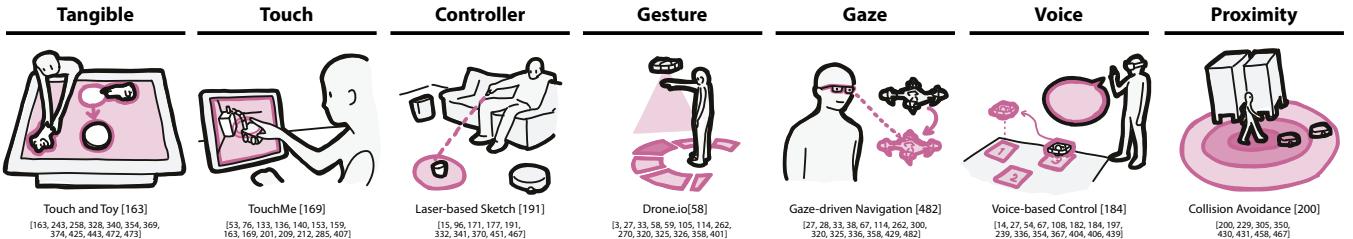


Figure 9: Interaction modalities and techniques

implicitly to the users' physical movements (e.g., approaching to the robot).

— *Explicit and Indirect Manipulation*: Indirect manipulation is the user's input through remote manipulation without any physical contact. The interaction can take place through pointing out objects [325], selecting and drawing [191], or explicitly determining actions with body motion (e.g., changing the setting in a virtual menu [58])

— *Explicit and Direct Physical Manipulation*: Finally, this category involves the user's direct touch inputs with their hands or bodies. The user can physically interact with the robots through embodied body interaction [369]. Several interaction techniques utilize the deformation of objects or robots [243], grasping and manipulating [163], or physically demonstrating [270].

Dimension-2. Interaction Modalities: Next, we synthesize categories based on the interaction modalities (Figure 9).

— *Tangible*: The user can interact with robots by changing the shape or by physically deforming the object [243, 258], moving robots by grasping and moving tangible objects [163, 340], or controlling robots by grasping and manipulating robots themselves [328].

— *Touch*: Touch interactions often involve the touch screen of mobiles, tablets, or other interactive surfaces. The user can interact with robots by dragging or drawing on a tablet [76, 209, 212], touching and pointing the target position [163], and manipulating virtual menus on a smartphone [53]. The touch interaction is particularly useful when requiring precise input for controlling [153, 169] or programming the robot's motion [136, 407].

— *Pointer and Controller*: The pointer and controller allow the user to manipulate robots through spatial interaction or device action. Since the controller provides tactile feedback, it reduces the effort to manipulate robots [171]. While many controller inputs are explicit interactions [191, 467], the user can also implicitly communicate with robots, such as designing a 3D virtual object with the pointer [341].

— *Spatial Gesture*: Spatial gestures are a common interaction modality for HMD-based interfaces [27, 33, 58, 59, 114, 262, 320, 326]. With these kinds of gestures, users can manipulate virtual way points [325, 358] or operate robots with a virtual menu [58]. The spatial gesture is also used to implicitly manipulate swarm robots through remote interaction [401].

— *Gaze*: Gaze is often used to accompany the spatial gesture [27, 114, 262, 300, 325, 358, 482], such as when performing menu selection [27]. But, some works investigate the gaze itself to control the robot by pointing out the location in 3D space [28].

— *Voice*: Some research leveraged voice input to execute commands for the robot operation [27, 182, 197, 354], especially in co-located settings.

— *Proximity*: Finally, proximity is used as an implicit form of interaction to communicate with robots [14, 182, 305]. For example, the AR's trajectory will be updated to show the robot's intent when a passerby approaches the robot [458]. Also, the shape-shifting wall can change the content on the robot based on the user's behavior and position [431].

9 APPLICATION DOMAINS

We identified a range of different application domains in AR and robotics. Figure 10 summarizes the each category and the list of related papers. We classified the existing works into the following high-level application-type clusters: 1) *domestic and everyday use*, 2) *industry applications*, 3) *entertainment*, 4) *education and training*, 5) *social interaction*, 6) *design and creative tasks*, 7) *medical and health*, 8) *telepresence and remote collaboration*, 9) *mobility and transportation*, 10) *search and rescue*, 11) *robots for workspaces*, and 12) *data physicalization*.

Detailed lists of application use cases within each of these categories can be found in Figure 10, as well as appendix, including detailed lists of references we identified. The largest category is *industry*. For example, industry application includes manufacturing, assembly, maintenance, and factory automation. In many of these cases, AR can help the user to reduce the assembly or maintenance workload or program the robots for automation. Another large category we found emerging is *domestic and everyday use scenarios*. For example, AR is used to program robots for household tasks. Also, there are some other sub-categories, such as photography, tour guide, advertisement, and wearable robots. *Games and entertainment* are popular with robotic user interfaces. In these examples, the combination of robots and AR is used to provide an immersive game experience, or used for storytelling, music, or museums. Figure 10 suggests that there are less explored application domains, which can be investigated in the future, which include design and creative tasks, remote collaboration, and workspace applications.

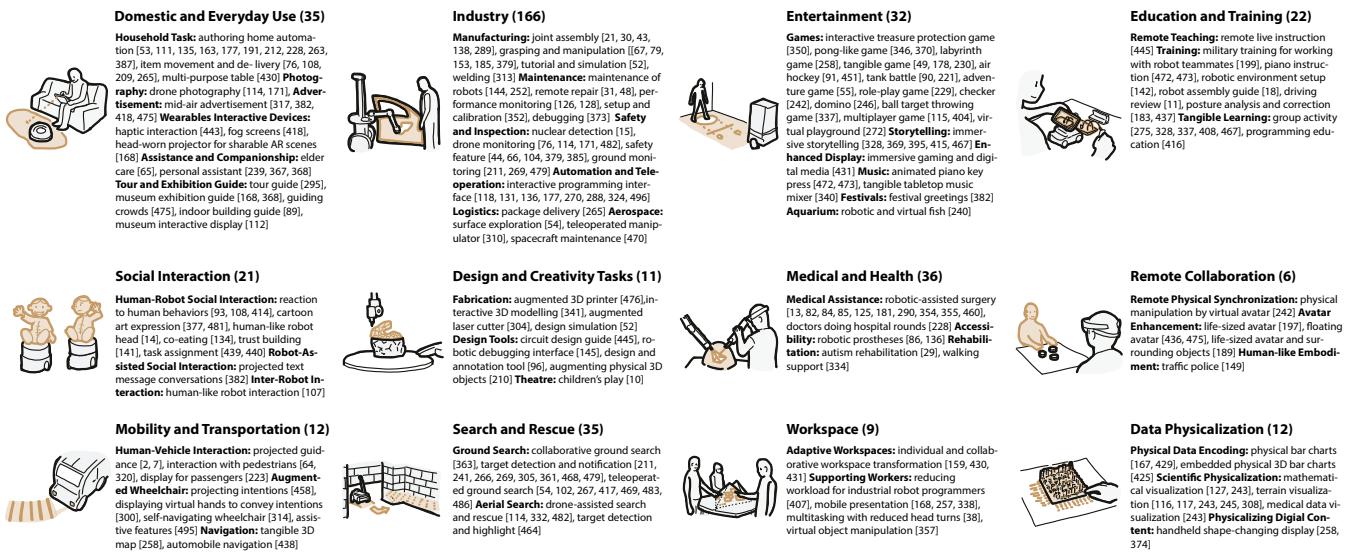


Figure 10: Use cases and application domains

10 EVALUATION STRATEGIES

In this section, we report our analysis of evaluation strategies for augmented reality and robotics. The main categories we identified are following the classification by Lledo et al. [236]: 1) evaluation through demonstration, (2) technical evaluations, and (3) user evaluations. The goal of this section is to help researchers finding the best technique to evaluate their systems, when designing AR for robotic systems.

Evaluation-1. Evaluation through Demonstration: *Evaluation through demonstration* is a technique to see how well a system will potentially work in certain situations. The most common approach from our findings include showing example applications [84, 127, 142, 209, 245, 325, 366, 382, 418, 476] and proof-of-concept demonstrations of a system [24, 55, 117, 162, 199, 221, 270, 305, 375, 479]. Other common approaches include demonstrating a system through a workshop [244, 246, 476], demonstrating the idea to a focus group [9, 367, 472, 492], carrying out case studies [105, 189, 324], and providing a conceptual idea [200, 367, 374, 472, 492].

Evaluation-2. Technical Evaluation: *Technical Evaluation* refers to how well a system performs based on internal technical measures of the system. The most common approaches for technical evaluation are measuring latency [48, 51, 59, 69, 318, 495], accuracy of tracking [15, 58, 59, 64, 486], and success rate [262, 314]. Also, we found some works evaluate their system performances based on the comparison with other systems, which for example, include comparing tracking algorithms with other approaches [38, 59, 63, 132, 406].

Evaluation-3. User Evaluation: *User evaluation* refers to measuring the effectiveness of a system through user studies. To measure the user performance when interacting with the system, there are many different approaches and methods that are used. For example, the NASA TLX questionnaire is a very popular technique for user evaluation [15, 63, 67, 69, 358], which can be found used mostly

for industry related applications. Other approaches include running quantitative [38, 171, 184] and qualitative [21, 138, 165] lab studies, through interviews [64, 103, 443] and questionnaires [48, 59, 495]. Sometimes systems combine user evaluations techniques with demonstration [111, 382] or technical evaluations [15, 406]. In observational studies [58, 369, 382], researchers can also get user feedback through observations [135, 448]. Finally, some systems also ran lab studies through expert interviews [10, 116, 340] to get specific feedback from the expert's perspectives.

11 DISCUSSION AND FINDINGS

Based on the analysis of our taxonomy, Figure 11 shows a summary of the number of papers for each dimension. In this section, we discuss common strategies and gaps across characteristics of selected dimensions.

Robot - Proximity Category: In terms of proximity, *co-located with distance* are the preferred method in AR-HRI systems (251 papers). This means that the current trend for AR-HRI systems is to have users co-located with the robot, but to not make any sort of contact with it. This also suggests that AR devices provide a promising way to interact with robots without having the need to directly make contact with it, such as performing robotic manipulation programming through AR [326].

Design - UI and Widget Category: In terms of the *Design - UI and Widgets* category, labels and annotations are the most common choice (241 papers) used in AR systems. Given that AR enables us to design visual feedback without many of the constraints of physical reality, researchers of AR-HRI systems take advantage of that fact to provide relevant information about the robot and/or other points of interest such as the environment and objects [96]. Increasingly, other widgets are used, such as information panels, floating displays, or menus. It is notable that only 24 papers made

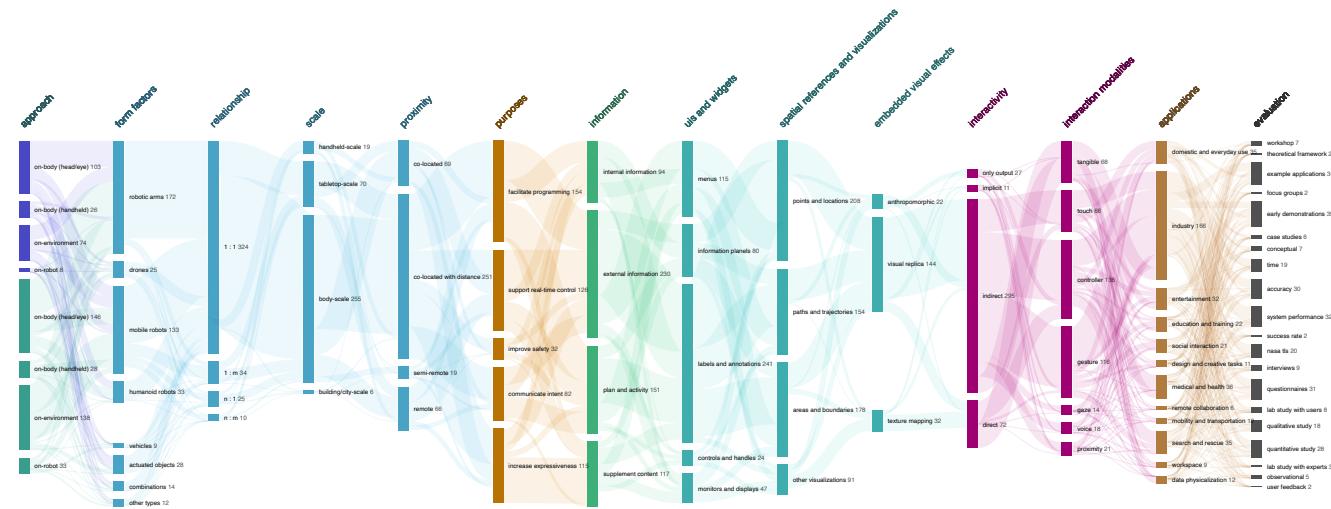


Figure 11: A visualization with overall counts of characteristics across all dimensions.

use of virtual control handles, possibly implying that AR is not yet commonly used for providing direct control to robots.

Interactions - Level of Interactivity Category: For the *Interaction Level* category, we observed that *explicit and indirect input* is the most common approach within AR-HRI systems (295 papers). This means that user input through AR to interact with the robot must go through some sort of input mapping to accurately interact with the robot. This is an area that should be further explored, which we mention in **Section 11 - Immersive Authoring and Prototyping Environments for AR-HRI**. However, while AR may not be the popular approach in terms of controlling a robot's movement, as mentioned above, it is still an effective medium to provide other sorts of input, such as path trajectories [358], for robots.

Interactions - Modality Category: In the *Interaction Modality* category, *pointers and controllers* (136 papers) and *spatial gestures* (116 papers) are most commonly used. Spatial gestures, for example, are used in applications such as robot gaming [273]. Furthermore, *touch* (66 papers) and *tangibles* (68 papers) are also common interaction modalities, indicating that these traditional forms of modality are seen as effective options for AR-HRI systems (for example, in applications such as medical robots [459] and collaborative robots [493]). It is promising to see how many AR-HRI systems are using tangible modalities to provide shape-changing elements [243] and control [340] to robots. Gaze and voice input are less common across the papers in our corpus, similar to proximity-based input, pointing to interesting opportunities for future work to explore these modalities in the AR-HRI context.

12 FUTURE OPPORTUNITIES

Finally, we formulate open research questions, challenges, and opportunities for AR and robotics research. For each opportunity, we also discuss potential research directions, providing sketches and relevant sections or references as a source of inspiration. We

hope this section will guide, inspire, and stimulate the future of AR-enhanced Human-Robot Interaction (AR-HRI) research.

Making AR-HRI Practical and Ubiquitous

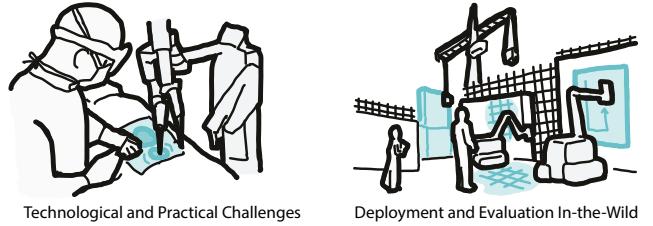


Figure 12: Opportunity-1: Making AR-HRI Practical and Ubiquitous. Left: Improvement of display and tracking technologies would broaden practical applications like robotic surgery. Right: Deployment in-the-wild outside the research lab, such as construction sites, would benefit from user-centered design.

Opportunity-1. Making AR-HRI Practical and Ubiquitous:

— **Technological and Practical Challenges:** While AR-HRI has a great promise, there are many technological and practical challenges ahead of us. For example, the accurate realistic superimposition or occlusion of virtual elements is still very challenging due to noisy real-time tracking. The **improvement of display and tracking technologies** would broaden the range of practical applications, especially when more precise alignments are needed, such as robotic-assisted surgery or medical applications (**Section 9.7**). Moreover, **error-reliable system design** is also important for practical applications. AR-HRI is used to improve safety for human co-workers (**Section 5.2**), however, if the AR system fails in such a safety-critical situation, users might be at risk (e.g., device malfunctions, content misalignment, obscured critical objects with inappropriate content overlap, etc.). It is important to **increase the reliability** of

AR systems from both systems design and user interaction perspectives (e.g., What extent should users rely on AR systems in case the system fails? How can we avoid visual clutter or the occlusion of critical information in a dangerous area? etc). These technical and practical challenges should be addressed before we can see AR devices be common in everyday life.

— *Deployment and Evaluation In-the-Wild*: Related to the above, most prior AR-HRI research has been done in controlled laboratory conditions. It is still questionable whether these systems and findings can be directly applied to a real-world situation. For example, outdoor scenarios like search-and-rescue or building construction (**Section 9**) may require very different technical requirements than indoor scenarios (e.g., Is projection mapping visible enough outdoors? Can outside-in tracking sufficiently cover the area that needs to be tracked?). On the other hand, the current HMD devices still have many usability and technical limitations, such as display resolution, visual comfort, battery life, weight, the field of view, and latency issues. To appropriately design a practical system for real-world applications, it is important to design based on the user’s needs through ***user-centered design*** by conducting a repeated cycle of interviews, prototyping, and evaluation. In particular, researchers need to carefully consider different approaches or technological choices (**Section 3**) to meet the user’s needs. The deployment and evaluation in the wild will allow us to develop a better understanding of what kind of designs or techniques should work and what should not in real-world situations.

Designing and Exploring New AR-HRI

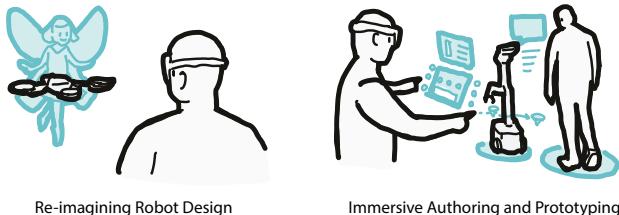


Figure 13: Opportunity-2: Designing and Exploring New AR-HRI. Left: AR-HRI can open up a new opportunity for unconventional robot design like fairy or fictional characters with the power of AR. Right: Immersive authoring tools allow us to prototype interactions through direct manipulation within AR.

Opportunity-2. Designing and Exploring New AR-HRI:

— *Re-imagining Robot Design without Physical Constraints*: With AR-HRI, we have a unique opportunity to *re-imagine robots design* without constraints of physical reality. For example, we have covered interesting attempts from the prior works, like *making non-humanoid robots humanoid* [180, 198, 481] or *making robots visually animated* [3, 14, 158] (**Section 7.3**), either through HMD [197] or projection [14] (**Section 3**). However, this is just the tip of the iceberg of such possibilities. For example, what if robots would look like a fictional character [57, 208] or behave like Disney’s character animation? [214, 434, 444] We believe there is still a huge untapped design

opportunity for ***augmented virtual skins*** of the robots by fully leveraging the unlimited visual expressions. In addition, there is also a rich design space of ***dynamic appearance change*** by leveraging visual illusion [259, 260], such as making robots disappear [299, 369], change color [152, 453], or transform its shape [170, 392, 424, 425] with the power of AR. By increasing the expressiveness of robots (**Section 5.5**), this could improve the engagement of the users and enable interesting applications (e.g., using drones that have facial expression [173] or human body/face [148] for remote telepresence [197]). We argue that there are still many opportunities for such ***unconventional robot design*** with expressive visual augmentation. We invite and encourage researchers to re-imagine such possibilities for the upcoming AR/MR era.

— *Immersive Authoring and Prototyping Environments for AR-HRI*: Prototyping functional AR-HRI systems is still very hard, given the high barrier of requirements in both software and hardware skills. Moreover, the development of such systems is pretty time-consuming—people need to continuously move back and forth between the computer screen and the real world, which hinders the rapid design exploration and evaluation. To address this, we need a better authoring and prototyping tool that allows ***even non-programmers*** to design and prototype to broaden the AR-HRI research community. For example, what if, users can design and prototype interactions ***through direct manipulation within AR***, rather than coding on a computer screen? (e.g., one metaphor is, for example, Figma for app development or Adobe Character Animator for animation) In such tools, users also must be able to design ***without the need for low-level robot programming***, such as actuation control, sensor access, and networking. Such AR authoring tools have been explored in the HCI context [40, 247, 311, 455] but still relatively unexplored in the domain of AR-HRI except for a few examples [51, 422]. We envision the future of intuitive authoring tools should invoke further design explorations of AR-HRI systems (**Section 7**) by democratizing the opportunity to the broader community.

AR-HRI for Better Decision-Making

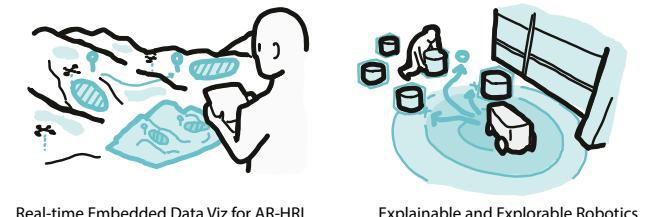


Figure 14: Opportunity-3: AR-HRI for Better Decision-Making. Left: Real-time embedded and immersive visualizations help an operator’s decision-making in drone navigation for search-and-rescue. Right: AR-based explainable robotics enables the user to understand a robot’s path planning behavior through physical explorations.

Opportunity-3. AR-HRI for Better Decision-Making:

— *Real-time Embedded Data Visualization for AR-HRI*: AR interfaces promise to support operators’ complex decision-making (**Section**

5.2) by aggregating and visualizing various data sources, such as internal, external, or goal-related information (**Section 6.1-6.3**). Currently, such visualizations are mainly limited with simple spatial references of user-defined data points (**Section 7.2**), but there is still a huge potential to connect data visualization to HRI [428] in the context of AR-HRI. For example, what if AR interfaces can ***directly embed real-time data onto the real world***, rather than on a computer screen? We could even combine real-time visualizations with a ***world-in-miniature*** [95] to facilitate navigation in a large area, such as drone navigation for search-and-rescue. We can take inspiration from existing immersive data analysis [70, 113] or real-time embedded data visualization research [423, 462, 463] to better design such data-centric interfaces for AR-HRI. We encourage the researchers to start thinking about how we can apply these emerging data visualization practices for AR-HRI systems in the future.

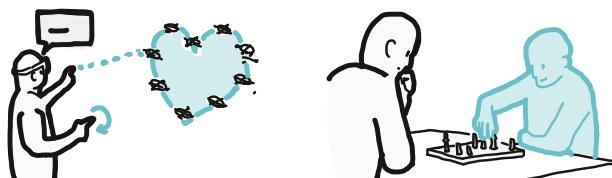
— ***Explainable and Explorable Robotics through AR-HRI***: As robots become more and more intelligent and autonomous, it becomes more important to make the robot's decision-making process visible and interpretable. This is often called ***Explainable AI*** in the context of machine learning and AI research, but it is also becoming relevant to robotics research as ***Explainable Robotics*** [97, 390]. Currently, such explanations are represented as descriptive text or visuals on a screen [97]. However, by leveraging AR-HRI systems, ***users can better understand the robots' behavior*** by seeing what they see (sensing), how they think (decision making), and how they respond (actions) in the real world. For example, what if users can see what a robot recognizes as obstacles or how it chooses the optimal path when navigating in a crowded place? More importantly, these visualizations are also ***explorable***—users can interactively explore to see how the robot's decision would change when the physical world changes (e.g., directly manipulating physical obstacles to see how the robot's optimal path updates). Such interfaces could help programmers, operators, or co-workers understand the robot's behavior more easily and interactively. Future research should ***connect explainable robotics with AR*** to better visualize the robot's decision-making process *embedded in real-world*.

Opportunity-4. Novel Interaction Design enabled by AR-HRI:

— ***Natural Input Interactions with AR-HRI Devices***: With the proliferation of HMD devices, it is now possible to use expressive inputs more casually and ubiquitously, including gesture, gaze, head, voice, and proximity-based interaction (**Section 8.2**). In contrast to environment-installed tracking, HMD-based hand- and gaze-tracking could enable more natural interactions without the constraint of location. For example, with the hand-tracking capability, we can now implement expressive gesture interactions, such as finger-snap, hand-waving, hand-pointing, and mid-air drawing for swarm drone controls in entertainment, search and rescue, firefighting, or agricultural foraging [17, 217]). In addition, the combination of multiple modalities, such as voice, gaze, and gesture is also an interesting direction. For example, when the user says “*Can you bring this to there?*”, it is usually difficult to clarify the ambiguity (e.g., “this” or “there”), but with the combination of gaze and gesture, it is much easier to clarify these ambiguities within the context. AR-based visual feedback could also help the user clarify their intentions. The user could even casually register or program such a new input on-demand through end-user robot programming (**Section 5.1**). Exploring new interactions enabled by AR-HRI systems is also an exciting opportunity.

— ***Further Blending the Virtual and Physical Worlds***: As robots weave themselves into the fabric of our everyday environment, the term “*robots*” no longer refer to only traditional humanoid or industry robots, but can become a variety of forms (**Section 2.1** and **Section 4.1**)—from self-driving cars [7] to robotic furniture [421, 478], wearable robots [99], haptic devices [449], shape-changing displays [127], and actuated interfaces [331]. These ubiquitous robots will be used to ***actuate our physical world*** to make the world more dynamic and reconfigurable. By leveraging both AR and this physical reconfigurability, we envision further blending virtual and physical worlds with a ***seamless coupling between pixels and atoms***. Currently, AR is only used to *visually augment* appearances of the physical world. However, what if ***AR can also “physically” affect the real-world***? For example, what if a *virtual user* pushes a physical wall then it moves synchronously? What if *virtual wind* can wave a physical cloth or flag? What if *virtual explosion* can make a shock wave collapse physical boxes? Such ***virtual-physical interactions*** would make AR more immersive with the power of visual illusion, which can also have some practical applications such as entertainment, remote collaboration, and education. Previously, such ideas were only partially explored [23, 401], but we believe there still remains a rich design space to be further explored. For future work, we should further seek to blend virtual and physical worlds by leveraging both visually (AR) and physically (robotic reconfiguration) programmable environments.

Novel Interaction Design Enabled by AR-HRI



Natural Input Interactions with AR-HRI

Blending the Virtual and Physical Worlds

Figure 15: Opportunity-4: Novel Interaction Design enabled by AR-HRI. Left: The user can interact with a swarm of drones with an expressive two-handed gesture like a mid-air drawing. Right: Programmable physical actuation and reconfiguration enable us to further blend the virtual and physical worlds, like a virtual remote user can “physically” move a chess piece with tabletop actuation.

13 CONCLUSION

In this paper, we present our survey results and taxonomy of AR and robotics, synthesizing existing research approaches and designs in the eight design space dimensions. Our goal is to provide a common ground for researchers to investigate the existing approaches and design of AR-HRI systems. In addition, to further stimulate the future of AR-HRI research, we discuss future research opportunities by pointing out eight possible directions: 1) technological

and practical challenges, 2) deployment and evaluation in-the-wild, 3) re-imagining robot design, 4) immersive authoring and prototyping environments, 5) real-time embedded data visualization for AR-HRI, 6) explainable and exploratory robotics with AR, 7) novel interactions techniques, and 8) further blending the virtual and physical worlds with programmable augmentation and actuation. We hope our survey, taxonomy, and open research opportunity will guide and inspire the future of AR and robotics research.

REFERENCES

- [1] 2014. List of Physical Visualizations and Related Artifacts. Retrieved on January 5, 2022 from <http://dataphys.org/list/>
- [2] 2015. The Mercedes-Benz F 015 luxury in motion. Retrieved on January 5, 2022 from <https://www.mercedes-benz.com/en/innovation/autonomous/research-vehicle-f-015-luxury-in-motion/>
- [3] 2015. Microsoft Hololens Robot Demo at Build 2015. Retrieved on January 5, 2022 from <https://www.youtube.com/watch?v=mSCrvIBGTeQ>
- [4] 2016. Boeing: UAVs. Holograms. Wildfire. Retrieved on January 5, 2022 from <https://www.youtube.com/watch?v=omGoz66xHU8>
- [5] 2017. Personal Fabrication Research in HCI and Graphics: An Overview of Related Work. Retrieved on January 5, 2022 from <https://hcie.csail.mit.edu/fabpub/>
- [6] 2018. MorphUI. Retrieved on January 5, 2022 from <http://morphui.com/>
- [7] 2019. Jaguar land rover lights up the road ahead for self-driving vehicles of the future. Retrieved on January 5, 2022 from <https://media.jaguarlandrover.com/news/2019/01/jaguar-land-rover-lights-road-ahead-self-driving-vehicles-future>
- [8] 2020. Nintendo Mario Kart Live: Home Circuit. Retrieved on January 5, 2022 from <https://mklive.nintendo.com/>
- [9] Syed Mohsin Abbas, Syed Hassan, and Jongwon Yun. 2012. Augmented reality based teaching pendant for industrial robot. In *2012 12th International Conference on Control, Automation and Systems*. IEEE, 2210–2213.
- [10] Jong-gil Ahn, Gerard J Kim, Hyemin Yeon, Eunja Hyun, and Kyoung Choi. 2013. Supporting augmented reality based children’s play with pro-cam robot: three user perspectives. In *Proceedings of the 12th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry*. 17–24. <https://doi.org/10.1145/2534329.2534342>
- [11] Yuya Aikawa, Masayoshi Kanoh, Felix Jimenez, Mitsuhiro Hayase, Takahiro Tanaka, and Hitoshi Kanamori. 2018. Comparison of gesture inputs for robot system using mixed reality to encourage driving review. In *2018 Joint 10th International Conference on Soft Computing and Intelligent Systems (SCIS) and 19th International Symposium on Advanced Intelligent Systems (ISIS)*. IEEE, 62–66. <https://doi.org/10.1109/scis-isis.2018.00020>
- [12] Batu Akan, Afshin Ameri, Baran Cürükli, and Lars Asplund. 2011. Intuitive industrial robot programming through incremental multimodal language and augmented reality. In *2011 IEEE International Conference on Robotics and Automation*. IEEE, 3934–3939. <https://doi.org/10.1109/icra.2011.5979887>
- [13] Takintope Akinbiyi, Carol E Reiley, Sunipa Saha, Darius Burschka, Christopher J Hasser, David D Yuh, and Allison M Okamura. 2006. Dynamic augmented reality for sensory substitution in robot-assisted surgical systems. In *2006 International Conference of the IEEE Engineering in Medicine and Biology Society*. IEEE, 567–570. <https://doi.org/10.1109/tembs.2006.259707>
- [14] Samer Al Moubayed, Jonas Beskow, Gabriel Skantze, and Björn Granström. 2012. Furhat: a back-projected human-like robot head for multiparty human-machine interaction. In *Cognitive behavioural systems*. Springer, 114–130. https://doi.org/10.1007/978-3-642-34584-5_9
- [15] Jacopo Aleotti, Giorgio Micconi, Stefano Caselli, Giacomo Benassi, Nicola Zambelli, Manuele Bettelli, and Andrea Zappettini. 2017. Detection of nuclear sources by UAV teleoperation using a visuo-haptic augmented reality interface. *Sensors* 17, 10 (2017), 2234. <https://doi.org/10.3390/s17102234>
- [16] Jason Alexander, Anne Roudaut, Jürgen Steimle, Kasper Hornbæk, Miguel Bruns Alonso, Sean Follmer, and Timothy Merritt. 2018. Grand challenges in shape-changing interface research. In *Proceedings of the 2018 CHI conference on human factors in computing systems*. 1–14. <https://doi.org/10.1145/3173574.3173873>
- [17] Omri Alon, Sharon Rabinovich, Chana Fyodorov, and Jessica R Cauchard. 2021. Drones in Firefighting: A User-Centered Design Perspective. In *Proceedings of the 23rd International Conference on Mobile Human-Computer Interaction*. 1–11. <https://doi.org/10.1145/3447526.3472030>
- [18] Malek Alrashidi, Ahmed Alzahrani, Michael Gardner, and Vic Callaghan. 2016. A pedagogical virtual machine for assembling mobile robot using augmented reality. In *Proceedings of the 7th Augmented Human International Conference 2016*. 1–2. <https://doi.org/10.1145/2875194.2875229>
- [19] Malek Alrashidi, Michael Gardner, and Vic Callaghan. 2017. Evaluating the use of pedagogical virtual machine with augmented reality to support learning embedded computing activity. In *Proceedings of the 9th International Conference on Computer and Automation Engineering*. 44–50. <https://doi.org/10.1145/3057039.3057088>
- [20] Alborz Amir-Khalili, Masoud S Nosrati, Jean-Marc Peyrat, Ghassan Hamarneh, and Rafeef Abugharbieh. 2013. Uncertainty-encoded augmented reality for robot-assisted partial nephrectomy: A phantom study. In *Augmented Reality Environments for Medical Imaging and Computer-Assisted Interventions*. Springer, 182–191. https://doi.org/10.1007/978-3-642-40843-4_20
- [21] Rasmus S Andersen, Ole Madsen, Thomas B Moeslund, and Heni Ben Amor. 2016. Projecting robot intentions into human environments. In *2016 25th IEEE International Symposium on Robot and Human Interactive Communication (ROMAN)*. IEEE, 294–301. <https://doi.org/10.1109/ROMAN.2016.7745145>
- [22] Sean Andrist, Tomislav Pejsa, Bilge Mutlu, and Michael Gleicher. 2012. Designing effective gaze mechanisms for virtual agents. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 705–714. <https://doi.org/10.1145/2207676.2207777>
- [23] Takafumi Aoki, Takashi Matsushita, Yuichiro Iio, Hironori Mitake, Takashi Toyama, Shoichi Hasegawa, Rikiya Ayukawa, Hiroshi Ichikawa, Makoto Sato, Takatsugu Kuriyama, et al. 2005. Kobito: virtual brownies. In *ACM SIGGRAPH 2005 emerging technologies*. 11–es. <https://doi.org/10.1145/1187297.1187309>
- [24] Dejanira Araiza-Illan, Alberto De San Bernabe, Fang Hongchao, and Leong Yong Shin. 2019. Augmented reality for quick and intuitive robotic packing re-programming. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 664–664. <https://doi.org/10.1109/hri.2019.8673327>
- [25] Stephanie Arévalo Arboleda, Tim Dierks, Franziska Rücker, and Jens Gerken. 2020. There’s More than Meets the Eye: Enhancing Robot Control through Augmented Visual Cues. In *Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*. 104–106. <https://doi.org/10.1145/3371382.3378240>
- [26] Stephanie Arévalo Arboleda, Tim Dierks, Franziska Rücker, and Jens Gerken. 2021. Exploring the Visual Space to Improve Depth Perception in Robot Teleoperation Using Augmented Reality: The Role of Distance and Target’s Pose in Time, Success, and Certainty. In *IFIP Conference on Human-Computer Interaction*. Springer, 522–543. https://doi.org/10.1007/978-3-030-85623-6_31
- [27] Stephanie Arévalo Arboleda, Franziska Rücker, Tim Dierks, and Jens Gerken. 2021. Assisting Manipulation and Grasping in Robot Teleoperation with Augmented Reality Visual Cues. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–14. <https://doi.org/10.1145/3411764.3445398>
- [28] Michael Argyle and Mark Cook. 1976. Gaze and mutual gaze. (1976). <https://doi.org/10.1017/S0007125000073980>
- [29] Pasquale Arpaia, Carmela Bravaccio, Giuseppina Corrado, Luigi Duraccio, Nicola Moccaldi, and Silvia Rossi. 2020. Robotic Autism Rehabilitation by Wearable Brain-Computer Interface and Augmented Reality. In *2020 IEEE International Symposium on Medical Measurements and Applications (MeMeA)*. IEEE, 1–6. <https://doi.org/10.1109/MeMeA49120.2020.9137144>
- [30] Doris Aschenbrenner, Jonas SI Rieder, Danielle Van Tol, Joris Van Dam, Zoltan Rusak, Jan Olaf Blech, Mohammad Azangoo, Salo Panu, Karl Kruusamäe, Houman Masnavi, et al. 2020. Mirrorlabs-creating accessible Digital Twins of robotic production environment with Mixed Reality. In *2020 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*. IEEE, 43–48. <https://doi.org/10.1109/aivr50618.2020.00007>
- [31] Doris Aschenbrenner, Michael Rojkov, Florian Leutert, Jouke Verlinden, Stephan Lukosch, Marc Erich Latoschik, and Klaus Schilling. 2018. Comparing different augmented reality support applications for cooperative repair of an industrial robot. In *2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. IEEE, 69–74. <https://doi.org/10.1109/ismar-adjunct.2018.00036>
- [32] Ronald T Azuma. 1997. A survey of augmented reality. *Presence: teleoperators & virtual environments* 6, 4 (1997), 355–385. <https://doi.org/10.1162/pres.1997.6.4.355>
- [33] Daniel Bambušek, Zdeněk Materna, Michal Kapinus, Vítězslav Beran, and Pavel Smrž. 2019. Combining interactive spatial augmented reality with head-mounted display for end-user collaborative robot programming. In *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 1–8. <https://doi.org/10.1109/RO-MAN4645.2019.8956315>
- [34] Kim Baraka, Ana Paiva, and Manuela Veloso. 2016. Expressive lights for revealing mobile service robot state. In *Robot 2015: Second Iberian Robotics Conference*. Springer, 107–119. https://doi.org/10.1007/978-3-319-27146-0_9
- [35] Zoltán Bárdosi, Christian Plattner, Yusuf Özpek, Thomas Hofmann, Srdjan Milosavljević, Volker Schartinger, and Wolfgang Freysinger. 2020. CIGuide: in situ augmented reality laser guidance. *International journal of computer assisted radiology and surgery* 15, 1 (2020), 49–57. <https://doi.org/10.1007/s11548-019-02066-1>
- [36] Patrick Baudisch, Stefanie Mueller, et al. 2017. Personal fabrication. *Foundations and Trends® in Human-Computer Interaction* 10, 3–4 (2017), 165–293. <https://doi.org/10.1561/1100000055>

- [37] Philipp Beckerle, Claudio Castellini, and Bigna Lenggenhager. 2019. Robotic interfaces for cognitive psychology and embodiment research: a research roadmap. *Wiley Interdisciplinary Reviews: Cognitive Science* 10, 2 (2019), e1486. <https://doi.org/10.1002/wcs.1486>
- [38] William Bentz, Sahib Dhanjal, and Dimitra Panagou. 2019. Unsupervised learning of assistive camera views by an aerial co-robot in augmented reality multi-tasking environments. In *2019 International Conference on Robotics and Automation (ICRA)*. IEEE, 3003–3009. <https://doi.org/10.1109/icra.2019.8793587>
- [39] Lorenzo Bianchi, Francesco Chessa, Andrea Angiolini, Laura Cercenelli, Simone Lodi, Barbara Bortolani, Enrico Molinaroli, Carlo Casablanca, Matteo Droghetti, Caterina Gaudiano, et al. 2021. The use of augmented reality to guide the intra-operative frozen section during robot-assisted radical prostatectomy. *European Urology* 80, 4 (2021), 480–488. <https://doi.org/10.1016/j.euro.2021.06.020>
- [40] Mark Billinghurst and Michael Nebeling. 2021. Rapid prototyping for XR. In *SIGGRAPH Asia 2021 Courses*, 1–178. <https://doi.org/10.1145/3476117.3483444>
- [41] Oliver Bimber and Ramesh Raskar. 2006. Modern approaches to augmented reality. In *ACM SIGGRAPH 2006 Courses*, 1–es. <https://doi.org/10.1145/1185657.1185796>
- [42] Sebastian Blankemeyer, Rolf Wiemann, Lukas Posniak, Christoph Pregizer, and Annika Raatz. 2018. Intuitive robot programming using augmented reality. *Procedia CIRP* 76 (2018), 155–160. <https://doi.org/10.1016/j.procir.2018.02.028>
- [43] Andrew Boateng and Yu Zhang. 2021. Virtual Shadow Rendering for Maintaining Situation Awareness in Proximal Human-Robot Teaming. In *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*, 494–498. <https://doi.org/10.1145/3434074.3447221>
- [44] Gabriele Bolano, Christian Juergl, Arne Roennau, and Ruediger Dillmann. 2019. Transparent robot behavior using augmented reality in close human-robot interaction. In *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 1–7. <https://doi.org/10.1109/roman46459.2019.8956296>
- [45] Gabriele Bolano, Arne Roennau, and Ruediger Dillmann. 2020. Planning and Evaluation of Robotic Solutions in a Logistic Line Through Augmented Reality. In *2020 Fourth IEEE International Conference on Robotic Computing (IRC)*. IEEE, 422–423. <https://doi.org/10.1109/irc.2020.00075>
- [46] Jean Botev and Francisco J Rodriguez Lera. 2021. Immersive Robotic Telepresence for Remote Educational Scenarios. *Sustainability* 13, 9 (2021), 4717. <https://doi.org/10.3390/SU13094717>
- [47] Gustavo Caiza, Pablo Bonilla-Vasconez, Carlos A Garcia, and Marcelo V Garcia. 2020. Augmented Reality for Robot Control in Low-cost Automation Context and IoT. In *2020 25th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, Vol. 1. IEEE, 1461–1464. <https://doi.org/10.1109/etfa46521.2020.9212056>
- [48] Davide Calandra, Alberto Cannavò, and Fabrizio Lamberti. 2021. Evaluating an Augmented Reality-Based Partially Assisted Approach to Remote Assistance in Heterogeneous Robotic Applications. In *2021 IEEE 7th International Conference on Virtual Reality (ICVR)*. IEEE, 380–387. <https://doi.org/10.1109/icvr51878.2021.9483849>
- [49] Daniel Calife, João Luiz Bernardes Jr, and Romero Tori. 2009. Robot Arena: An augmented reality platform for game development. *Computers in Entertainment (CIE)* 7, 1 (2009), 1–26. <https://doi.org/10.1145/1486508.1486519>
- [50] Laura Cancedda, Alberto Cannavò, Giuseppe Garofalo, Fabrizio Lamberti, Paolo Montuschi, and Gianluca Paravati. 2017. Mixed-reality-based user interaction feedback for a hand-controlled interface targeted to robot teleoperation. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*. Springer, 447–463. https://doi.org/10.1007/978-3-319-60928-7_38
- [51] Yuanzhi Cao, Tianyi Wang, Xun Qian, Pawan S Rao, Manav Wadhwani, Ke Huo, and Karthik Ramani. 2019. GhostAR: A time-space editor for embodied authoring of human-robot collaborative task with augmented reality. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*, 521–534. <https://doi.org/10.1145/332165.3347902>
- [52] Yuanzhi Cao, Zhuangying Xu, Terrell Glenn, Ke Huo, and Karthik Ramani. 2018. Ani-Bot: A Modular Robotics System Supporting Creation, Tweaking, and Usage with Mixed-Reality Interactions. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction*, 419–428. <https://doi.org/10.1145/3173225.3173226>
- [53] Yuanzhi Cao, Zhuangying Xu, Fan Li, Wentao Zhong, Ke Huo, and Karthik Ramani. 2019. V. Ra: An in-situ visual authoring system for robot-IoT task planning with augmented reality. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, 1059–1070. <https://doi.org/10.1145/3322276.3322278>
- [54] Irvin Steve Cardenas, Kaleb Powlison, and Jong-Hoon Kim. 2021. Reducing Cognitive Workload in Telepresence Lunar-Martian Environments Through Audiovisual Feedback in Augmented Reality. In *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*, 463–466. <https://doi.org/10.1145/3434074.3447214>
- [55] Jon Carroll and Fabrizio Polo. 2013. Augmented reality gaming with sphero. In *ACM Siggraph 2013 Mobile*, 1–1. <https://doi.org/10.1145/2503512.2503535>
- [56] Giandomenico Caruso and Paolo Bellucco. 2010. Robotic arm for car dashboard layout assessment in mixed reality environment. In *19th International Symposium in Robot and Human Interactive Communication*. IEEE, 62–68. <https://doi.org/10.1109/ROMAN.2010.5598685>
- [57] Jessica Cauchard, Woody Gover, William Chen, Stephen Cartwright, and Ehud Sharlin. 2021. Drones in Wonderland—Disentangling Collocated Interaction Using Radical Form. *IEEE Robotics and Automation Letters* (2021). <https://doi.org/10.1109/lra.2021.3103653>
- [58] Jessica R Cauchard, Alex Tamkin, Cheng Yao Wang, Luke Vink, Michelle Park, Tommy Fang, and James A Landay. 2019. Drone. io: A gestural and visual interface for human-drone interaction. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 153–162. <https://doi.org/10.1109/HRI19.8673011>
- [59] Elizabeth Cha, Naomi T Fitter, Yunkyoung Kim, Terrence Fong, and Maja J Matarić. 2018. Effects of Robot Sound on Auditory Localization in Human-Robot Collaboration. In *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 434–442. <https://doi.org/10.1145/3171221.3171285>
- [60] Elizabeth Cha and Maja Matarić. 2016. Using nonverbal signals to request help during human-robot collaboration. In *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 5070–5076. <https://doi.org/10.1109/IROS.2016.7759744>
- [61] Sonia Mary Chacko, Armando Granado, and Vikram Kapila. 2020. An augmented reality framework for robotic tool-path teaching. *Procedia CIRP* 93 (2020), 1218–1223. <https://doi.org/10.1016/j.procir.2020.03.143>
- [62] Sonia Mary Chacko, Armando Granado, Ashwin RajKumar, and Vikram Kapila. 2020. An Augmented Reality Spatial Referencing System for Mobile Robots. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 4446–4452. <https://doi.org/10.1109/iros45743.2020.9340742>
- [63] Sonia Mary Chacko and Vikram Kapila. 2019. An augmented reality interface for human-robot interaction in unconstrained environments. In *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 3222–3228. <https://doi.org/10.1109/iros40897.2019.8967973>
- [64] Ravi Teja Chadalavada, Henrik Andreasson, Maike Schindler, Rainer Palm, and Achim J Lilienthal. 2020. Bi-directional navigation intent communication using spatial augmented reality and eye-tracking glasses for improved safety in human-robot interaction. *Robotics and Computer-Integrated Manufacturing* 61 (2020), 101830. <https://doi.org/10.1016/j.rcim.2019.101830>
- [65] Seungho Chae, Hyocheol Ro, Yoonsik Yang, and Tack-Don Han. 2018. A Pervasive Assistive Robot System Including Projection-Camera Technology for Older Adults. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*, 83–84. <https://doi.org/10.1145/3173386.3177007>
- [66] Tathagata Chakraborti, Sarah Sreedharan, Anagha Kulkarni, and Subbarao Kambhampati. 2018. Projection-aware task planning and execution for human-in-the-loop operation of robots in a mixed-reality workspace. In *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 4476–4482. <https://doi.org/10.1109/IROS.2018.8593830>
- [67] Wesley P Chan, Geoffrey Hanks, Maram Sakr, Tiger Zuo, HF Machiel Van der Loos, and Elizabeth Croft. 2020. An augmented reality human-robot physical collaboration interface design for shared, large-scale, labour-intensive manufacturing tasks. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 11308–11313. <https://doi.org/10.1109/IROS45743.2020.9341119>
- [68] Wesley P Chan, Adnan Karim, Camilo P Quintero, HF Machiel Van der Loos, and Elizabeth Croft. 2018. Virtual barriers in augmented reality for safe human-robot collaboration in manufacturing. In *Robotic Co-Workers 4.0 2018: Human Safety and Comfort in Human-Robot Interactive Social Environments*.
- [69] Wesley P Chan, Maram Sakr, Camilo Perez Quintero, Elizabeth Croft, and HF Machiel Van der Loos. 2020. Towards a Multimodal System combining Augmented Reality and Electromyography for Robot Trajectory Programming and Execution. In *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 419–424. <https://doi.org/10.1109/ROMAN47096.2020.9223526>
- [70] Tom Chandler, Maxime Cordeil, Tobias Czauderma, Tim Dwyer, Jaroslaw Glowacki, Cagatay Goncu, Matthias Klapperstueck, Karsten Klein, Kim Marriott, Falk Schreiber, et al. 2015. Immersive analytics. In *2015 Big Data Visual Analytics (BDVA)*. IEEE, 1–8. <https://doi.org/10.1109/TVC.2019.2929033>
- [71] Chih-Wei Chang, Jih-Hsien Lee, Chin-Yeh Wang, and Gwo-Dong Chen. 2010. Improving the authentic learning experience by integrating robots into the mixed-reality environment. *Computers & Education* 55, 4 (2010), 1572–1578. <https://doi.org/10.1016/j.compedu.2010.06.023>
- [72] Siam Charoenseeang and Tarinee Tonggoed. 2011. Human-robot collaboration with augmented reality. In *International Conference on Human-Computer Interaction*. Springer, 93–97. https://doi.org/10.1007/978-3-642-22095-1_19
- [73] Hua Chen, Oliver Wulf, and Bernardo Wagner. 2006. Object detection for a mobile robot using mixed reality. In *International Conference on Virtual Systems and Multimedia*. Springer, 466–475. https://doi.org/10.1007/11890881_51
- [74] Ian Yen-Hung Chen, Bruce MacDonald, Burkhard Wünsche, Geoffrey Biggs, and Tetsuo Kotoku. 2010. Analysing mixed reality simulation for industrial applications: A case study in the development of a robotic screw remover

- system. In *International Conference on Simulation, Modeling, and Programming for Autonomous Robots*. Springer, 350–361. https://doi.org/10.1007/978-3-642-17319-6_33
- [75] Linfeng Chen, Akiyuki Ebi, Kazuki Takashima, Kazuyuki Fujita, and Yoshifumi Kitamura. 2019. PinpointFly: An egocentric position-pointing drone interface using mobile AR. In *SIGGRAPH Asia 2019 Emerging Technologies*. 34–35. <https://doi.org/10.1145/3355049.3360534>
- [76] Linfeng Chen, Kazuki Takashima, Kazuyuki Fujita, and Yoshifumi Kitamura. 2021. PinpointFly: An Egocentric Position-control Drone Interface using Mobile AR. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–13. <https://doi.org/10.1145/3411764.3445110>
- [77] Long Chen, Fengfeng Zhang, Wei Zhan, Minfeng Gan, and Lining Sun. 2020. Optimization of virtual and real registration technology based on augmented reality in a surgical navigation system. *Biomedical engineering online* 19, 1 (2020), 1–28. <https://doi.org/10.1186/s12938-019-0745-z>
- [78] Mingxuan Chen, Ping Zhang, Zebo Wu, and Xiaodan Chen. 2020. A multichannel human-swarm robot interaction system in augmented reality. *Virtual Reality & Intelligent Hardware* 2, 6 (2020), 518–533. <https://doi.org/10.1016/j.vrih.2020.006>
- [79] Xiaogang Chen, Xiaoshan Huang, Yijun Wang, and Xiaorong Gao. 2020. Combination of augmented reality based brain-computer interface and computer vision for high-level control of a robotic arm. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 28, 12 (2020), 3140–3147. <https://doi.org/10.1109/ttsre.2020.3038209>
- [80] Zhe Chen, Zhuohang Cao, Peili Ma, and Lijun Xu. 2020. Industrial Robot Training Platform Based on Virtual Reality and Mixed Reality Technology. In *International Conference on Man-Machine-Environment System Engineering*. Springer, 891–898. https://doi.org/10.1007/978-981-15-6978-4_102
- [81] Vijay Chidambaram, Yueh-Hsuan Chiang, and Bülge Mutlu. 2012. Designing persuasive robots: how robots might persuade people using vocal and nonverbal cues. In *Proceedings of the seventh annual ACM/IEEE international conference on Human-Robot Interaction*. 293–300. <https://doi.org/10.1145/2157689.2157798>
- [82] Seung Wook Choi, Hee Chan Kim, Heung Sik Kang, Seongjun Kim, and Jaesoон Choi. 2013. A haptic augmented reality surgeon console for a laparoscopic surgery robot system. In *2013 13th International Conference on Control, Automation and Systems (ICCAS 2013)*. IEEE, 355–357. <https://doi.org/10.1109/iccas.2013.6703923>
- [83] Jonathan Wun Shiung Chong, SKC Ong, Andrew YC Nee, and KB Youcef-Youmi. 2009. Robot programming using augmented reality: An interactive method for planning collision-free paths. *Robotics and Computer-Integrated Manufacturing* 25, 3 (2009), 689–701. <https://doi.org/10.1016/j.rcim.2008.05.002>
- [84] Wusheng Chou, Tianmiao Wang, and Yuru Zhang. 2004. Augmented reality based preoperative planning for robot assisted tele-neurosurgery. In *2004 IEEE International Conference on Systems, Man and Cybernetics (IEEE Cat. No. 04CH37583)*, Vol. 3. IEEE, 2901–2906. <https://doi.org/10.1109/icsmc.2004.1400773>
- [85] Nicklas H Christensen, Oliver G Hjermitslev, Frederik Falk, Marco B Madsen, Frederik H Østergaard, Martin Kibsgaard, Martin Kraus, Johan Poulsen, and Jane Petersson. 2017. Depth cues in augmented reality for training of robot-assisted minimally invasive surgery. In *Proceedings of the 21st International Academic Mindtrek Conference*. 120–126. <https://doi.org/10.1145/3131085.3131123>
- [86] Francesco Clemente, Strahinja Dosen, Luca Lonini, Marko Markovic, Dario Farina, and Christian Cipriani. 2016. Humans can integrate augmented reality feedback in their sensorimotor control of a robotic hand. *IEEE Transactions on Human-Machine Systems* 47, 4 (2016), 583–589. <https://doi.org/10.1109/thms.2016.2611998>
- [87] Marcelo Coelho and Jamie Zigelbaum. 2011. Shape-changing interfaces. *Personal and Ubiquitous Computing* 15, 2 (2011), 161–173. <https://doi.org/10.1007/s00779-010-0311-y>
- [88] Michael D Coover, Tiffany Lee, Ivan Shindev, and Yu Sun. 2014. Spatial augmented reality as a method for a mobile robot to communicate intended movement. *Computers in Human Behavior* 34 (2014), 241–248. <https://doi.org/10.1016/j.chb.2014.02.001>
- [89] Austin Corotan and Jianna Jian Zhang Irgen-Gioro. 2019. An Indoor Navigation Robot Using Augmented Reality. In *2019 5th International Conference on Control, Automation and Robotics (ICCAR)*. IEEE, 111–116. <https://doi.org/10.1109/iccar.2019.8813348>
- [90] Hugo Costa, Peter Cebola, Tiago Cunha, and Armando Sousa. 2015. A mixed reality game using 3Pi robots—“PiTanks”. In *2015 10th Iberian Conference on Information Systems and Technologies (CISTI)*. IEEE, 1–6. <https://doi.org/10.1109/CISTI.2015.7170600>
- [91] Nuno Costa and Artur Arsenio. 2015. Augmented reality behind the wheel-human interactive assistance by mobile robots. In *2015 6th International Conference on Automation, Robotics and Applications (ICARA)*. IEEE, 63–69. <https://doi.org/10.1109/ICARA.2015.7081126>
- [92] Ève Coste-Manière, Louai Adhami, Fabien Mourges, and Alain Carpentier. 2003. Planning, simulation, and augmented reality for robotic cardiac procedures: The STARS system of the ChIR team. In *Seminars in thoracic and cardiovascular surgery*, Vol. 15. Elsevier, 141–156. [https://doi.org/10.1016/S1043-0679\(03\)70022-7](https://doi.org/10.1016/S1043-0679(03)70022-7)
- [93] Matthew Cousins, Chenguang Yang, Junshen Chen, Wei He, and Zhaojie Ju. 2017. Development of a mixed reality based interface for human robot interaction. In *2017 International Conference on Machine Learning and Cybernetics (ICMLC)*, Vol. 1. IEEE, 27–34. <https://doi.org/10.1109/icmlc.2017.8107738>
- [94] Oscar Danielsson, Anna Syberfeldt, Rodney Brewster, and Lihui Wang. 2017. Assessing instructions in augmented reality for human-robot collaborative assembly by using demonstrators. *Procedia CIRP* 63 (2017), 89–94. <https://doi.org/10.1016/j.procir.2017.02.038>
- [95] Kurtis Danyluk, Barrett Ens, Bernhard Jenny, and Wesley Willett. 2021. A Design Space Exploration of Worlds in Miniature. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–15. <https://doi.org/10.1145/3411764.3445098>
- [96] Rajkumar Darbar, Joan Sol Roo, Thibault Lainé, and Martin Hatchet. 2019. Drone-SAR: extending physical spaces in spatial augmented reality using projection on a drone. In *Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia*. 1–7. <https://doi.org/10.1145/3365610.3365631>
- [97] Devleena Das, Siddhartha Banerjee, and Sonia Chernova. 2021. Explainable ai for robot failures: Generating explanations that improve user assistance in fault recovery. In *Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*. 351–360. <https://doi.org/10.1145/3434073.3444657>
- [98] Alessandro De Franco, Edoardo Lamon, Pietro Balatti, Elena De Momi, and Arash Ajoudani. 2019. An Intuitive augmented reality interface for task scheduling, monitoring, and work performance improvement in human-robot collaboration. In *2019 IEEE International Work Conference on Bioinspired Intelligence (IWobi)*. IEEE, 75–80. <https://doi.org/10.1109/iwobi47054.2019.9114472>
- [99] Artem Dementyev, Hsin-Liu Kao, Inrak Choi, Deborah Ajilo, Maggie Xu, Joseph A Paradiso, Chris Schmandt, and Sean Follmer. 2016. Rovables: Miniature on-body robots as mobile wearables. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*. 111–120. <https://doi.org/10.1145/2984511.2984531>
- [100] Morteza Dianatfar, Jyrki Latokartano, and Minna Lanz. 2021. Review on existing VR/AR solutions in human-robot collaboration. *Procedia CIRP* 97 (2021), 407–411. <https://doi.org/10.1016/j.procir.2020.05.259>
- [101] Adhitha Dias, Hasitha Wellaboda, Yasod Rasanka, Menusha Munasinghe, Ranga Rodrigo, and Peshala Jayasekara. 2020. Deep Learning of Augmented Reality-based Human Interactions for Automating a Robot Team. In *2020 6th International Conference on Control, Automation and Robotics (ICCAR)*. IEEE, 175–182. <https://doi.org/10.1109/iccar49639.2020.9108004>
- [102] Tiago Dias, Pedro Miraldo, Nuno Gonçalves, and Pedro U Lima. 2015. Augmented reality on robot navigation using non-central catadioptric cameras. In *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 4999–5004. <https://doi.org/10.1109/iros.2015.7354080>
- [103] Maximilian Diehl, Alexander Plopksi, Hirokazu Kato, and Karinne Ramirez-Amaro. 2020. Augmented Reality interface to verify Robot Learning. In *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 378–383. <https://doi.org/10.1109/ro-man47096.2020.9223502>
- [104] André Dietrich, Michael Schulze, Sebastian Zug, and Jörg Kaiser. 2010. Visualization of robot's awareness and perception. In *Proceedings of the First International Workshop on Digital Engineering*. 38–44. <https://doi.org/10.1145/1837154.1837160>
- [105] Huynh Dinh, Quilong Yuan, Iastrebov Vietcheslav, and Gerald Seet. 2017. Augmented reality interface for taping robot. In *2017 18th International Conference on Advanced Robotics (ICAR)*. IEEE, 275–280. <https://doi.org/10.1109/ICAR.2017.8023530>
- [106] Anca D Dragan, Kenton CT Lee, and Siddhartha S Srinivasa. 2013. Legibility and predictability of robot motion. In *2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 301–308. <https://doi.org/10.1109/HRI.2013.6483603>
- [107] Mauro Dragone, Thomas Holz, and Gregory MP O'Hare. 2006. Mixing robotic realities. In *Proceedings of the 11th international conference on Intelligent user interfaces*. 261–263. <https://doi.org/10.1145/1111449.1111504>
- [108] Mauro Dragone, Thomas Holz, and Gregory MP O'Hare. 2007. Using mixed reality agents as social interfaces for robots. In *RO-MAN 2007-The 16th IEEE International Symposium on Robot and Human Interactive Communication*. IEEE, 1161–1166. <https://doi.org/10.1109/roman.2007.4415255>
- [109] Mauro Dragone, Thomas Holz, GMP O'Hare, and Michael J O'Grady. 2009. Mixed Reality Agents (MiRA) Chameleons. In *Agent-Based Ubiquitous Computing*. Springer, 13–33. https://doi.org/10.2991/978-94-91216-31-2_2
- [110] Philip Edgecumbe, Rohit Singla, Philip Pratt, Caitlin Schneider, Christopher Nguan, and Robert Rohling. 2016. Augmented reality imaging for robot-assisted partial nephrectomy surgery. In *International Conference on Medical Imaging and Augmented Reality*. Springer, 139–150. https://doi.org/10.1007/978-3-319-43775-0_13
- [111] Lotfi El Hafi, Hitoshi Nakamura, Akira Taniguchi, Yoshinobu Hagiwara, and Tadahiro Taniguchi. 2021. Teaching system for multimodal object categorization by human-robot interaction in mixed reality. In *2021 IEEE/SICE International Symposium on System Integration (SII)*. IEEE, 320–324. <https://doi.org/10.1109/sii52021.9537009>

- IEEECONF49454.2021.9382607
- [112] Ahmed Elsharkawy, Khawar Naheem, Dongwoo Koo, and Mun Sang Kim. 2021. A UWB-Driven Self-Actuated Projector Platform for Interactive Augmented Reality Applications. *Applied Sciences* 11, 6 (2021), 2871. <https://doi.org/10.3390/app11062871>
- [113] Barrett Ens, Benjamin Bach, Maxime Cordeil, Ulrich Engelke, Marcos Serrano, Wesley Willett, Arnaud Prouzeau, Christoph Anthes, Wolfgang Büschel, Cody Dunne, et al. 2021. Grand challenges in immersive analytics. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–17. <https://doi.org/10.1145/3411764.3446866>
- [114] Okan Erat, Werner Alexander Isop, Denis Kalkofen, and Dieter Schmalstieg. 2018. Drone-augmented human vision: Exocentric control for drones exploring hidden areas. *IEEE transactions on visualization and computer graphics* 24, 4 (2018), 1437–1446. <https://doi.org/10.1109/TVCG.2018.2794058>
- [115] David Estevez, Juan G Victores, Santiago Morante, and Carlos Balaguer. 2015. Robot devastation: Using DIY low-cost platforms for multiplayer interaction in an augmented reality game. In *2015 7th International Conference on Intelligent Technologies for Interactive Entertainment (INTETAIN)*. IEEE, 32–36. <https://doi.org/10.4108/icst.intetain.2015.259753>
- [116] Aluna Everitt and Jason Alexander. 2017. PolySurface: a design approach for rapid prototyping of shape-changing displays using semi-solid surfaces. In *Proceedings of the 2017 Conference on Designing Interactive Systems*. 1283–1294. <https://doi.org/10.1145/3064663.3064677>
- [117] Aluna Everitt and Jason Alexander. 2019. 3D Printed Deformable Surfaces for Shape-Changing Displays. *Frontiers in Robotics and AI* 6 (2019), 80. <https://doi.org/10.3389/frobt.2019.00080>
- [118] A Eylampev and M Ostanin. 2019. Obstacle avoidance for robotic manipulator using Mixed reality glasses. In *2019 3rd School on Dynamics of Complex Networks and their Application in Intellectual Robotics (DCN AIR)*. IEEE, 46–48. <https://doi.org/10.1109/dcnair.2019.8875555>
- [119] Volkmar Falk, Fabien Mourgues, Louai Adhami, Stefan Jacobs, Holger Thiele, Stefan Nitzsche, Friedrich W Mohr, and Ève Coste-Manière. 2005. Cardio navigation: planning, simulation, and augmented reality in robotic assisted endoscopic bypass grafting. *The Annals of thoracic surgery* 79, 6 (2005), 2040–2047. <https://doi.org/10.1016/J.JTHORACCSUR.2004.11.060>
- [120] HC Fang, SK Ong, and AYC Nee. 2012. Interactive robot trajectory planning and simulation using augmented reality. *Robotics and Computer-Integrated Manufacturing* 28, 2 (2012), 227–237. <https://doi.org/10.1016/J.RCIM.2011.09.003>
- [121] HC Fang, SK Ong, and AYC Nee. 2012. Robot path and end-effector orientation planning using augmented reality. *Procedia CIRP* 3 (2012), 191–196. <https://doi.org/10.1016/j.procir.2012.07.034>
- [122] HC Fang, SK Ong, and AYC Nee. 2013. Orientation planning of robot end-effector using augmented reality. *The International Journal of Advanced Manufacturing Technology* 67, 9–12 (2013), 2033–2049. <https://doi.org/10.1007/S00170-012-4629-7>
- [123] HC Fang, SK Ong, and AYC Nee. 2014. A novel augmented reality-based interface for robot path planning. *International Journal on Interactive Design and Manufacturing (IJIDeM)* 8, 1 (2014), 33–42. <https://doi.org/10.1007/S12008-013-0191-2>
- [124] Hongchao Fang, Soh Khim Ong, and Andrew Yeh-Ching Nee. 2009. Robot programming using augmented reality. In *2009 International Conference on CyberWorlds*. IEEE, 13–20. <https://doi.org/10.1109/CW.2009.14>
- [125] Federica Ferraguti, Marco Minelli, Saverio Farsoni, Stefano Bazzani, Marcello Bonfè, Alexandre Vandanjon, Stefano Pulitati, Giampaolo Bianchi, and Christian Secchi. 2020. Augmented reality and robotic-assistance for percutaneous nephrolithotomy. *IEEE robotics and automation letters* 5, 3 (2020), 4556–4563. <https://doi.org/10.1109/lra.2020.3002216>
- [126] Michael Filipenko, Alexander Poeppl, Alwin Hoffmann, Wolfgang Reif, Andreas Monden, and Markus Sause. 2020. Virtual commissioning with mixed reality for next-generation robot-based mechanical component testing. In *ISR 2020; 52th International Symposium on Robotics*. VDE, 1–6. <https://doi.org/10.14236/EWIC/EVA2008.3>
- [127] Sean Follmer, Daniel Leithinger, Alex Olwal, Akimitsu Hogge, and Hiroshi Ishii. 2013. inFORM: dynamic physical affordances and constraints through shape and object actuation.. In *Uist*, Vol. 13. 2501988–2502032. <https://doi.org/10.1145/2501988.2502032>
- [128] Jason Fong, Renz Ocampo, Douglas P Gross, and Mahdi Tavakoli. 2019. A robot with an augmented-reality display for functional capacity evaluation and rehabilitation of injured workers. In *2019 IEEE 16th International Conference on Rehabilitation Robotics (ICORR)*. IEEE, 181–186. <https://doi.org/10.1109/icorr.2019.8779417>
- [129] Jutta Fortmann, Tim Claudius Stratmann, Susanne Boll, Benjamin Poppinga, and Wilko Heuten. 2013. Make me move at work! An ambient light display to increase physical activity. In *2013 7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops*. IEEE, 274–277. <https://doi.org/10.4108/icst.pervasivehealth.2013.252089>
- [130] Jared A Frank and Vikram Kapila. 2016. Towards teleoperation-based interactive learning of robot kinematics using a mobile augmented reality interface on a tablet. In *2016 Indian Control Conference (ICC)*. IEEE, 385–392. <https://doi.org/10.1109/indiancc.2016.7441163>
- [131] Jared Alan Frank, Sai Prasanth Krishnamoorthy, and Vikram Kapila. 2017. Toward mobile mixed-reality interaction with multi-robot systems. *IEEE Robotics and Automation Letters* 2, 4 (2017), 1901–1908. <https://doi.org/10.1109/LRA.2017.2714128>
- [132] Jared A Frank, Matthew Moorhead, and Vikram Kapila. 2016. Realizing mixed-reality environments with tablets for intuitive human-robot collaboration for object manipulation tasks. In *2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 302–307. <https://doi.org/10.1109/ROMAN.2016.7745146>
- [133] Jared A Frank, Matthew Moorhead, and Vikram Kapila. 2017. Mobile mixed-reality interfaces that enhance human–robot interaction in shared spaces. *Frontiers in Robotics and AI* 4 (2017), 20. <https://doi.org/10.3389/frobt.2017.00020>
- [134] Ayaka Fujii, Kanae Kochigami, Shingo Kitagawa, Kei Okada, and Masayuki Inaba. 2020. Development and Evaluation of Mixed Reality Co-eating System: Sharing the Behavior of Eating Food with a Robot Could Improve Our Dining Experience. In *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 357–362. <https://doi.org/10.1109/ro-man47096.2020.9223518>
- [135] Richard Fung, Sunao Hashimoto, Masahiko Inami, and Takeo Igarashi. 2011. An augmented reality system for teaching sequential tasks to a household robot. In *2011 RO-MAN*. IEEE, 282–287. <https://doi.org/10.1109/roman.2011.6005235>
- [136] Anna Fuste, Ben Reynolds, James Hobin, and Valentin Heun. 2020. Kinetic AR: A Framework for Robotic Motion Systems in Spatial Computing. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–8. <https://doi.org/10.1145/3334480.3382814>
- [137] Samir Yitzhak Gadre, Eric Rosen, Gary Chien, Elizabeth Phillips, Stefanie Tellex, and George Konidaris. 2019. End-user robot programming using mixed reality. In *2019 International conference on robotics and automation (ICRA)*. IEEE, 2707–2713. <https://doi.org/10.1109/icra.2019.8793988>
- [138] Ramsundar Kalpagam Ganesan, Yash K Rathore, Heather M Ross, and Heni Ben Amor. 2018. Better teaming through visual cues: how projecting imagery in a workspace can improve human-robot collaboration. *IEEE Robotics & Automation Magazine* 25, 2 (2018), 59–71. <https://doi.org/10.1109/mra.2018.2815655>
- [139] Peng Gao, Brian Reily, Savannah Paul, and Hao Zhang. 2020. Visual reference of ambiguous objects for augmented reality-powered human-robot communication in a shared workspace. In *International Conference on Human-Computer Interaction*. Springer, 550–561. https://doi.org/10.1007/978-3-030-49695-1_37
- [140] Yuxiang Gao and Chien-Ming Huang. 2019. PATI: a projection-based augmented table-top interface for robot programming. In *Proceedings of the 24th international conference on intelligent user interfaces*. 345–355. <https://doi.org/10.1145/3301275.3302326>
- [141] Yuan Gao, Elena Sibirtseva, Ginevra Castellano, and Danica Kragic. 2019. Fast adaptation with meta-reinforcement learning for trust modelling in human-robot interaction. In *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 305–312. <https://doi.org/10.1109/IROS40897.2019.8967924>
- [142] Abraham Prieto García, Gervasio Varela Fernández, Blanca María Priego Torres, and Fernando López-Peña. 2011. Educational autonomous robotics setup using mixed reality. In *2011 7th International Conference on Next Generation Web Services Practices*. IEEE, 452–457. <https://doi.org/10.1109/nwesp.2011.6088222>
- [143] Andre Gaschler, Maximilian Springer, Markus Rickerl, and Alois Knoll. 2014. Intuitive robot tasks with augmented reality and virtual obstacles. In *2014 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 6026–6031. <https://doi.org/10.1109/icra.2014.6907747>
- [144] Hakan GENCTÜRK and Uğur YAYAN. [n.d.]. Development of Augmented Reality Based Mobile Robot Maintenance Software. In *2019 Innovations in Intelligent Systems and Applications Conference (ASYU)*. IEEE, 1–5. <https://doi.org/10.1109/asyu48272.2019.8946359>
- [145] Fabrizio Ghiringhelli, Jérôme Guzzi, Gianni A Di Caro, Vincenzo Caglioti, Luca M Gambardella, and Alessandro Giusti. 2014. Interactive augmented reality for understanding and analyzing multi-robot systems. In *2014 IEEE/RSJ International Conference on Intelligent Robots and Systems*. IEEE, 1195–1201. <https://doi.org/10.1109/iros.2014.6942709>
- [146] Mario Gianni, Federico Ferri, and Fiora Pirri. 2013. ARE: Augmented reality environment for mobile robots. In *Conference Towards Autonomous Robotic Systems*. Springer, 470–483. https://doi.org/10.1007/978-3-662-43645-5_48
- [147] Fabio Giannone, Emanuele Felli, Zineb Cherkaoui, Pietro Mascagni, and Patrick Pessaux. 2021. Augmented Reality and Image-Guided Robotic Liver Surgery. *Cancers* 13, 24 (2021), 6268. <https://doi.org/10.3390/cancers13246268>
- [148] Antonio Gomes, Calvin Rubens, Sean Braley, and Roel Vertegaal. 2016. Bit-drones: Towards using 3d nanocopter displays as interactive self-levitating programmable matter. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 770–780. <https://doi.org/10.1145/2858036.2858519>
- [149] Liang Gong, Changyang Gong, Zhao Ma, Lujie Zhao, Zhenyu Wang, Xudong Li, Xiaolong Jing, Haozhe Yang, and Chengliang Liu. 2017. Real-time human-in-the-loop remote control for a life-size traffic police robot with multiple augmented reality aided display terminals. In *2017 2nd International Conference on Advanced*

- Robotics and Mechatronics (ICARM)*. IEEE, 420–425. <https://doi.org/10.1109/icarm.2017.8273199>
- [150] LL Gong, SK Ong, and AYC Nee. 2019. Projection-based augmented reality interface for robot grasping tasks. In *Proceedings of the 2019 4th International Conference on Robotics, Control and Automation*. 100–104. <https://doi.org/10.1145/3351180.3351204>
- [151] Michael A Goodrich and Alan C Schultz. 2008. *Human-robot interaction: a survey*. Now Publishers Inc. <https://doi.org/10.1561/1100000005>
- [152] Gregory R Gossweiler, Cameron L Brown, Gihan B Hewage, Eitan Sapiro-Gheiler, William J Trautman, Garrett W Welshofer, and Stephen L Craig. 2015. Mechanochemically active soft robots. *ACS applied materials & interfaces* 7, 40 (2015), 22431–22435. <https://doi.org/10.1021/acsami.5b06440>
- [153] Michael Gradmann, Eric M Orendt, Edgar Schmidt, Stephan Schweizer, and Dominik Henrich. 2018. Augmented reality robot operation interface with Google Tango. In *ISR 2018; 50th International Symposium on Robotics*. VDE, 1–8.
- [154] Keith Evan Green. 2016. *Architectural robotics: ecosystems of bits, bytes, and biology*. MIT Press.
- [155] Scott A Green, Mark Billinghurst, XiaoQi Chen, and J Geoffrey Chase. 2008. Human-robot collaboration: A literature review and augmented reality approach in design. *International journal of advanced robotic systems* 5, 1 (2008), 1. <https://doi.org/10.5772/5664>
- [156] Scott A Green, Xiao Qi Chen, Mark Billinghurst, and J Geoffrey Chase. 2008. Collaborating with a mobile robot: An augmented reality multimodal interface. *IFAC Proceedings Volumes* 41, 2 (2008), 15595–15600. <https://doi.org/10.3182/20080706-5-KR-1001.02637>
- [157] Santiago Grijalva and Wilbert G Aguilar. 2019. Landmark-Based Virtual Path Estimation for Assisted UAV FPV Tele-Operation with Augmented Reality. In *International Conference on Intelligent Robotics and Applications*. Springer, 688–700. https://doi.org/10.1007/978-3-030-27529-7_58
- [158] Thomas Groechel, Zhonghao Shi, Roxanna Pakkar, and Maja J Matarić. 2019. Using socially expressive mixed reality arms for enhancing low-expressivity robots. In *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 1–8. <https://doi.org/10.1109/ro-man46459.2019.8956458>
- [159] Jens Emil Grønbæk, Majken Kirkegaard Rasmussen, Kim Halskov, and Marianne Graves Petersen. 2020. KirigamiTable: Designing for proxemic transitions with a shape-changing tabletop. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–15. <https://doi.org/10.1145/3313831.3376834>
- [160] Uwe Gruenefeld, Lars Prädel, Jannike Illing, Tim Stratmann, Sandra Drolshagen, and Max Pfingsthorn. 2020. Mind the ARm: realtime visualization of robot motion intent in head-mounted augmented reality. In *Proceedings of the Conference on Mensch und Computer*. 259–266. <https://doi.org/10.1145/3404983.3405509>
- [161] Jan Guhl, Johannes Hügle, and Jörg Krüger. 2018. Enabling human-robot-interaction via virtual and augmented reality in distributed control systems. *Procedia CIRP* 76 (2018), 167–170. <https://doi.org/10.1016/J.PROCIR.2018.01.029>
- [162] Jan Guhl, Son Tung, and Jörg Kruger. 2017. Concept and architecture for programming industrial robots using augmented reality with mobile devices like microsoft HoloLens. In *2017 22nd IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*. IEEE, 1–4. <https://doi.org/10.1109/etfa.2017.8247749>
- [163] Cheng Guo, James Everett Young, and Ehud Sharlin. 2009. Touch and toys: new techniques for interaction with a remote group of robots. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 491–500. <https://doi.org/10.1145/1518701.1518780>
- [164] Akihiro Hamada, Atsuro Sawada, Jin Kono, Masanao Koeda, Katsuhiko Onishi, Takashi Kobayashi, Toshinari Yamasaki, Takahiro Inoue, Hiroshi Noborio, and Osamu Ogawa. 2020. The current status and challenges in augmented-reality navigation system for robot-assisted laparoscopic partial nephrectomy. In *International Conference on Human-Computer Interaction*. Springer, 620–629. https://doi.org/10.1007/978-3-030-49062-1_42
- [165] Jared Hamilton, Thao Phung, Nhan Tran, and Tom Williams. 2021. What's The Point? Tradeoffs Between Effectiveness and Social Perception When Using Mixed Reality to Enhance Gesturally Limited Robots. In *Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*. 177–186. <https://doi.org/10.1145/3434073.3444676>
- [166] Jeonghye Han, Miheon Jo, Eunja Hyun, and Hyo-Jeong So. 2015. Examining young children's perception toward augmented reality-infused dramatic play. *Educational Technology Research and Development* 63, 3 (2015), 455–474. <https://doi.org/10.1007/S11423-015-9374-9>
- [167] John Hardy, Christian Weichel, Faisal Taher, John Vidler, and Jason Alexander. 2015. Shapeclip towards rapid prototyping with shape-changing displays for designers. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 19–28. <https://doi.org/10.1145/2702123.2702599>
- [168] Jeremy Hartmann, Yen-Ting Yeh, and Daniel Vogel. 2020. AAR: Augmenting a wearable augmented reality display with an actuated head-mounted projector. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*. 445–458. <https://doi.org/10.1145/3379337.3415849>
- [169] Sunao Hashimoto, Akihiko Ishida, Masahiko Inami, and Takeo Igarashi. 2011. Touchme: An augmented reality based remote robot manipulation. In *The 21st International Conference on Artificial Reality and Telexistence, Proceedings of ICAT2011*, Vol. 2.
- [170] Hooman Hedayati, Ryo Suzuki, Daniel Leithinger, and Daniel Szafir. 2020. Pufferbot: Actuated expandable structures for aerial robots. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 1338–1343. <https://doi.org/10.1109/iros45743.2020.9341088>
- [171] Hooman Hedayati, Michael Walker, and Daniel Szafir. 2018. Improving collocated robot teleoperation with augmented reality. In *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. 78–86. <https://doi.org/10.1145/3171221.3171251>
- [172] Mary Hegarty, Matt S Canham, and Sara I Fabrikant. 2010. Thinking about the weather: How display salience and knowledge affect performance in a graphic inference task. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 36, 1 (2010), 37. <https://doi.org/10.1037/a0017683>
- [173] Viviane Herdel, Anastasia Kuzminykh, Andrea Hildebrandt, and Jessica R Cauchard. 2021. Drone in Love: Emotional Perception of Facial Expressions on Flying Robots. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–20. <https://doi.org/10.1145/3411764.3445495>
- [174] Juan David Hernández, Shlok Sobti, Anthony Sciola, Mark Moll, and Lydia E Kavraki. 2020. Increasing robot autonomy via motion planning and an augmented reality interface. *IEEE Robotics and Automation Letters* 5, 2 (2020), 1017–1023. <https://doi.org/10.1109/lra.2020.2967280>
- [175] Takayuki Hirai, Satoshi Nakamaru, Yoshihiro Kawahara, and Yasuaki Kakehi. 2018. xslate: A stiffness-controlled surface for shape-changing interfaces. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–4. <https://doi.org/10.1145/3170427.3186496>
- [176] Takefumi Hiraki, Shogo Fukushima, Yoshihiro Kawahara, and Takeshi Naemura. 2018. Phygital field: An integrated field with physical robots and digital images using projection-based localization and control method. *SICE Journal of Control, Measurement, and System Integration* 11, 4 (2018), 302–311. <https://doi.org/10.9746/jcmsi.11.302>
- [177] Takefumi Hiraki, Shogo Fukushima, Yoshihiro Kawahara, and Takeshi Naemura. 2019. NavigaTorch: Projection-based Robot Control Interface using High-speed Handheld Projector. In *SIGGRAPH Asia 2019 Emerging Technologies*. 31–33. <https://doi.org/10.1145/3355049.3360538>
- [178] Takefumi Hiraki, Shogo Fukushima, and Takeshi Naemura. 2016. Phygital field: an integrated field with a swarm of physical robots and digital images. In *SIGGRAPH ASIA 2016 Emerging Technologies*. 1–2. <https://doi.org/10.1145/2988240.2988242>
- [179] Takefumi Hiraki, Issei Takahashi, Shotaro Goto, Shogo Fukushima, and Takeshi Naemura. 2015. Phygital field: integrated field with visible images and robot swarm controlled by invisible images. In *ACM SIGGRAPH 2015 Posters*. 1–1. <https://doi.org/10.1145/2787626.2792604>
- [180] Yutaki Hiroi, Shuhei Hisano, and Akinori Ito. 2010. Evaluation of head size of an interactive robot using an augmented reality. In *2010 World Automation Congress*. IEEE, 1–6. <https://doi.org/10.1109/ro-man46459.2010.8956315>
- [181] Tzu-Hsuan Ho and Kai-Tai Song. 2020. Supervised control for robot-assisted surgery using augmented reality. In *2020 20th International Conference on Control, Automation and Systems (ICCAS)*. IEEE, 329–334. <https://doi.org/10.23919/ICCAS50221.2020.9268278>
- [182] Khoa Cong Hoang, Wesley P Chan, Steven Lay, Akansel Cosgun, and Elizabeth Croft. 2021. Virtual Barriers in Augmented Reality for Safe and Effective Human-Robot Cooperation in Manufacturing. *arXiv preprint arXiv:2104.05211* (2021).
- [183] Ayanna M Howard, Luke Roberts, Sergio Garcia, and Rakale Quarrells. 2012. Using mixed reality to map human exercise demonstrations to a robot exercise coach. In *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, 291–292. <https://doi.org/10.1109/ismar.2012.6402579>
- [184] Baichuan Huang, Deniz Bayazit, Daniel Ullman, Nakul Gopalan, and Stefanie Tellex. 2019. Flight, camera, action! using natural language and mixed reality to control a drone. In *2019 International Conference on Robotics and Automation (ICRA)*. IEEE, 6949–6956. <https://doi.org/10.1109/ICRA.2019.8794200>
- [185] Bidan Huang, Nicholas Gerard Timmons, and Qiang Li. 2020. Augmented reality with multi-view merging for robot teleoperation. In *Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*. 260–262. <https://doi.org/10.1145/3371382.3378336>
- [186] Chien-Ming Huang and Bilge Mutlu. 2013. Modeling and Evaluating Narrative Gestures for Humanlike Robots.. In *Robotics: Science and Systems*. 57–64. <https://doi.org/10.15607/RSS.2013.IX.026>
- [187] Tianqi Huang, Ruiyang Li, Yangxi Li, Xinran Zhang, and Hongen Liao. 2021. Augmented reality-based autostereoscopic surgical visualization system for telesurgery. *International Journal of Computer Assisted Radiology and Surgery* 16, 11 (2021), 1985–1997. <https://doi.org/10.1007/s11548-021-02463-5>
- [188] Dinh Quang Huy, I Vietcheslav, and Gerald Seet Gim Lee. 2017. See-through and spatial augmented reality-a novel framework for human-robot interaction. In *2017 3rd International Conference on Control, Automation and Robotics (ICCAR)*. IEEE, 719–726. <https://doi.org/10.1109/ICCAR.2017.7942791>

- [189] Jane Hwang, Sangyup Lee, Sang Chul Ahn, and Hyoung-gon Kim. 2008. Augmented robot agent: Enhancing co-presence of the remote participant. In *2008 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*. IEEE, 161–162. <https://doi.org/10.1109/ismar.2008.4637346>
- [190] Hisham Iqbal, Fabio Tatti, and Ferdinando Rodriguez y Baena. 2021. Augmented reality in robotic assisted orthopaedic surgery: A pilot study. *Journal of Biomedical Informatics* 120 (2021), 103841. <https://doi.org/10.1016/j.jbi.2021.103841>
- [191] Kentaro Ishii, Shengdong Zhao, Masahiko Inami, Takeo Igarashi, and Michita Imai. 2009. Designing laser gesture interface for robot control. In *IFIP Conference on Human-Computer Interaction*. Springer, 479–492. https://doi.org/10.1007/978-3-642-03658-3_52
- [192] Yvonne Jansen, Pierre Dragicevic, Petra Isenberg, Jason Alexander, Abhijit Karanic, Johan Kildal, Sriram Subramanian, and Kasper Hornbæk. 2015. Opportunities and challenges for data physicalization. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 3227–3236. <https://doi.org/10.1145/2702123.2702180>
- [193] Yunwoo Jeong, Han-Jong Kim, and Tek-Jin Nam. 2018. Mechanism perfboard: An augmented reality environment for linkage mechanism design and fabrication. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–11. <https://doi.org/10.1145/3173574.3173985>
- [194] Zhenrui Ji, Quan Liu, Wenjun Xu, Bitao Yao, Jiayi Liu, and Zude Zhou. 2021. A Closed-Loop Brain-Computer Interface with Augmented Reality Feedback for Industrial Human-Robot Collaboration. (2021). <https://doi.org/10.21203/RS.3.RS-283263/V1>
- [195] Chun Jia and Zhenzhong Liu. 2020. Collision Detection Based on Augmented Reality for Construction Robot. In *2020 5th International Conference on Advanced Robotics and Mechatronics (ICARM)*. IEEE, 194–197. <https://doi.org/10.1109/icarm49381.2020.9195301>
- [196] Jingang Jiang, Yafeng Guo, Zhiyuan Huang, Yongde Zhang, Dianhao Wu, and Yi Liu. 2021. Adjacent surface trajectory planning of robot-assisted tooth preparation based on augmented reality. *Engineering Science and Technology, an International Journal* (2021). <https://doi.org/10.1016/J.JESTCH.2021.05.005>
- [197] Brennan Jones, Yaying Zhang, Priscilla NY Wong, and Sean Rintel. 2020. VROOM: Virtual Robot Overlay for Online Meetings. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–10. <https://doi.org/10.1145/3334480.3382820>
- [198] Brennan Jones, Yaying Zhang, Priscilla NY Wong, and Sean Rintel. 2021. Belonging There: VROOM-ing into the Uncanny Valley of XR Telepresence. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW1 (2021), 1–31. <https://doi.org/10.1145/3449133>
- [199] Colin Jones, Michael Novitzky, and Christopher Korpela. 2021. AR/VR Tutorial System for Human-Robot Teaming. In *2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC)*. IEEE, 0878–0882. <https://doi.org/10.1109/ccwc51732.2021.9375845>
- [200] Jana Jost, Thomas Kirks, Preity Gupta, Dennis Lünisch, and Jonas Stenzel. 2018. Safe human-robot-interaction in highly flexible warehouses using augmented reality and heterogeneous fleet management system. In *2018 IEEE International Conference on Intelligence and Safety for Robotics (ISR)*. IEEE, 256–260. <https://doi.org/10.1109/ISRS.2018.8535808>
- [201] Kevin Sebastian Kain, Susanne Stadler, Manuel Giuliani, Nicole Mirlig, Gerald Stollnberger, and Manfred Tschelegi. 2017. Tablet-based augmented reality in the factory: Influence of knowledge in computer programming on robot teaching tasks. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*. 151–152. <https://doi.org/10.1145/3029798.3038347>
- [202] Alisa Kalegina, Grace Schroeder, Aidan Allchin, Keara Berlin, and Maya Cakmak. 2018. Characterizing the design space of rendered robot faces. In *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 96–104. <https://doi.org/10.1145/3171221.3171286>
- [203] Megha Kalia, Apeksha Avinash, Nassir Navab, and Septimiu Salcudean. 2021. Preclinical evaluation of a markerless, real-time, augmented reality guidance system for robot-assisted radical prostatectomy. *International Journal of Computer Assisted Radiology and Surgery* (2021), 1–8. <https://doi.org/10.1007/s11548-021-02419-9>
- [204] Megha Kalia, Prateek Mathur, Keith Tsang, Peter Black, Nassir Navab, and Septimiu Salcudean. 2020. Evaluation of a marker-less, intra-operative, augmented reality guidance system for robot-assisted laparoscopic radical prostatectomy. *International Journal of Computer Assisted Radiology and Surgery* 15 (2020), 1225–1233. <https://doi.org/10.1007/s11548-020-02181-4>
- [205] Kenji Kansaku, Naoki Hata, and Kouji Takano. 2010. My thoughts through a robot's eyes: An augmented reality-brain-machine interface. *Neuroscience research* 66, 2 (2010), 219–222. <https://doi.org/10.1016/j.neures.2009.10.006>
- [206] Michal Kapinus, Vítězslav Beran, Zdeněk Materna, and Daniel Bambušek. 2019. Spatially Situated End-User Robot Programming in Augmented Reality. In *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 1–8. <https://doi.org/10.1109/RO-MAN46459.2019.8956336>
- [207] Michal Kapinus, Zdeněk Materna, Daniel Bambušek, and Vítězslav Beran. 2020. End-User Robot Programming Case Study: Augmented Reality vs. Teach Pendant. In *Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*. 281–283. <https://doi.org/10.1145/3371382.3378266>
- [208] Mohamed Kari, Tobias Grosse-Puppendahl, Luis Falconeri Coelho, Andreas Rene Fender, David Bethge, Reinhard Schütte, and Christian Holz. 2021. TransformMR: Pose-Aware Object Substitution for Composing Alternate Mixed Realities. In *2021 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. IEEE, 69–79. <https://doi.org/10.1109/ismar52148.2021.00021>
- [209] Shunichi Kasahara, Ryuma Niizuma, Valentin Heun, and Hiroshi Ishii. 2013. exTouch: spatially-aware embodied manipulation of actuated objects mediated by augmented reality. In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction*. 223–228. <https://doi.org/10.1145/2460625.2460661>
- [210] Misaki Kasetani, Tomonobu Noguchi, Hirotake Yamazoe, and Joo-Ho Lee. 2015. Projection mapping by mobile projector robot. In *2015 12th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*. IEEE, 13–17. <https://doi.org/10.1109/URAL2015.7358918>
- [211] Linh Kästner and Jens Lambrecht. 2019. Augmented-reality-based visualization of navigation data of mobile robots on the microsoft hololens—possibilities and limitations. In *2019 IEEE International Conference on Cybernetics and Intelligent Systems (CIS) and IEEE Conference on Robotics, Automation and Mechatronics (RAM)*. IEEE, 344–349. <https://doi.org/10.1109/cis-ram47153.2019.9095836>
- [212] Jun Kato, Daisuke Sakamoto, Masahiko Inami, and Takeo Igarashi. 2009. Multi-touch interface for controlling multiple mobile robots. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems*. 3443–3448. <https://doi.org/10.1145/1520340.1520500>
- [213] Yuta Kato, Yuya Aikawa, Masayoshi Kanoh, Felix Jimenez, Mitsuhiro Hayase, Takahiro Tanaka, and Hitoshi Kanamori. 2019. A Robot System Using Mixed Reality to Encourage Driving Review. In *International Conference on Human-Computer Interaction*. Springer, 112–117. https://doi.org/10.1007/978-3-030-23528-4_16
- [214] Rubaiat Habib Kazi, Tovi Grossman, Nobuyuki Umetani, and George Fitzmaurice. 2016. Motion amplifiers: sketching dynamic illustrations using the principles of 2D animation. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 4599–4609. <https://doi.org/10.1145/2858036.2858386>
- [215] Maram Khatib, Khaled Al Khudir, and Alessandro De Luca. 2021. Human-robot contactless collaboration with mixed reality interface. *Robotics and Computer-Integrated Manufacturing* 67 (2021), 102030. <https://doi.org/10.1016/j.rcim.2020.102030>
- [216] Hyoungnyoun Kim, Jun-Sik Kim, Kwanghyun Ryu, Seyoung Cheon, Yonghwan Oh, and Ji-Hyung Park. 2014. Task-oriented teleoperation through natural 3D user interaction. In *2014 11th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*. IEEE, 335–338. <https://doi.org/10.1109/urai.2014.7057536>
- [217] Lawrence H Kim, Daniel S Drew, Veronika Domova, and Sean Follmer. 2020. User-defined swarm robot control. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13. <https://doi.org/10.1145/3313831.3376814>
- [218] Lawrence H Kim and Sean Follmer. 2017. Ubiswarm: Ubiquitous robotic interfaces and investigation of abstract motion as a display. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 3 (2017), 1–20. <https://doi.org/10.1145/3130931>
- [219] Won S Kim. 1996. Virtual reality calibration and preview/predictive displays for telerobotics. *Presence: Teleoperators & Virtual Environments* 5, 2 (1996), 173–190.
- [220] Kazuhiko Kobayashi, Koichi Nishiwaki, Shinji Uchiyama, Hiroyuki Yamamoto, Satoshi Kagami, and Takeo Kanade. 2007. Overlay what humanoid robot perceives and thinks to the real-world by mixed reality system. In *2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality*. IEEE, 275–276. <https://doi.org/ismar.2007.4538864>
- [221] Minoru Kojima, Maki Sugimoto, Akihiro Nakamura, Masahiro Tomita, Hideaki Nii, and Masahiko Inami. 2006. Augmented coliseum: An augmented game environment with small vehicles. In *First IEEE International Workshop on Horizontal Interactive Human-Computer Systems (TABLETOP'06)*. IEEE, 6–pp. <https://doi.org/10.1109/TABLETOP.2006.3>
- [222] Abhishek Kolagunda, Scott Sorenson, Sherif Mehralivand, Philip Saponaro, Wayne Treible, Baris Turkbey, Peter Pinto, Peter Choyke, and Chandra Kamhametu. 2018. A mixed reality guidance system for robot assisted laparoscopic radical prostatectomy. In *OR 2.0 Context-Aware Operating Theaters, Computer Assisted Robotic Endoscopy, Clinical Image-Based Procedures, and Skin Image Analysis*. Springer, 164–174. https://doi.org/10.1007/978-3-030-01201-4_18
- [223] Andreas Korthauer, Clemens Guenther, Andreas Hinrichs, Wen Ren, and Yi-wen Yang. 2020. Watch Your Vehicle Driving at the City: Interior HMI with Augmented Reality for Automated Driving. In *22nd International Conference on Human-Computer Interaction with Mobile Devices and Services*. 1–5. <https://doi.org/10.1145/3406324.3425895>
- [224] Tomáš Kot, Petr Novák, and Ján Babjak. 2017. Application of augmented reality in mobile robot teleoperation. In *International Workshop on Modelling and Simulation for Autonomous Systems*. Springer, 223–236. https://doi.org/10.1007/978-3-319-76072-8_16

- [225] Niki Kousi, Christos Stoubos, Christos Gkournelos, George Michalos, and Sotiris Makris. 2019. Enabling human robot interaction in flexible robotic assembly lines: An augmented reality based software suite. *Procedia CIRP* 81 (2019), 1429–1434. <https://doi.org/10.1016/J.PROCIR.2019.04.328>
- [226] Dennis Krupke, Frank Steinicke, Paul Lubos, Yannick Jonetzko, Michael Görner, and Jianwei Zhang. 2018. Comparison of multimodal heading and pointing gestures for co-located mixed reality human-robot interaction. In *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 1–9. <https://doi.org/10.1109/iros.2018.8594043>
- [227] Aleksander Krzywinski, Haipeng Mi, Weiqin Chen, and Masanori Sugimoto. 2009. RoboTable: a tabletop framework for tangible interaction with robots in a mixed reality. In *proceedings of the international conference on advances in computer Entertainment technology*. 107–114. <https://doi.org/10.1145/1690388.1690407>
- [228] Eranda Lakshantha and Simon Egerton. 2014. Human Robot Interaction and Control: Translating Diagrams into an Intuitive Augmented Reality Approach. In *2014 International Conference on Intelligent Environments*. IEEE, 111–116. <https://doi.org/10.1109/ie.2014.24>
- [229] Fabrizio Lamberti, Davide Calandria, Federica Bazzano, Filippo G Prattico, and Davide M Destefanis. 2018. Robotquest: A robotic game based on projected mixed reality and proximity interaction. In *2018 IEEE Games, Entertainment, Media Conference (GEM)*. IEEE, 1–9. <https://doi.org/10.1109/GEM.2018.8516501>
- [230] Fabrizio Lamberti, Alberto Cannavò, and Paolo Pirone. 2019. Designing interactive robotic games based on mixed reality technology. In *2019 IEEE International Conference on Consumer Electronics (ICCE)*. IEEE, 1–4. <https://doi.org/10.1109/icce.2019.8661911>
- [231] Jens Lambrecht, Linh Kästner, Jan Guhl, and Jörg Krüger. 2021. Towards commissioning, resilience and added value of Augmented Reality in robotics: Overcoming technical obstacles to industrial applicability. *Robotics and Computer-Integrated Manufacturing* 71 (2021), 102178. <https://doi.org/10.1016/J.RCIM.2021.102178>
- [232] Jens Lambrecht and Jörg Krüger. 2012. Spatial programming for industrial robots based on gestures and augmented reality. In *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*. IEEE, 466–472. <https://doi.org/10.1109/IROS.2012.6385900>
- [233] Matheus Laranjeira, Aurélien Arnaubec, Lorenzo Brignone, Claire Dune, and Jan Opderbecke. 2020. 3D Perception and Augmented Reality Developments in Underwater Robotics for Ocean Sciences. *Current Robotics Reports* (2020), 1–8. <https://doi.org/10.1007/s43154-020-00014-5>
- [234] Tomas Lazna. 2018. The visualization of threats using the augmented reality and a remotely controlled robot. *IFAC-PapersOnLine* 51, 6 (2018), 444–449. <https://doi.org/10.1016/J.IFACOL.2018.07.113>
- [235] Mathieu Le Goc, Lawrence H Kim, Ali Parsaei, Jean-Daniel Fekete, Pierre Dragicevic, and Sean Follmer. 2016. Zoids: Building blocks for swarm user interfaces. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*. 97–109. <https://doi.org/10.1145/2984511.2984547>
- [236] David Ledo, Steven Houben, Jo Vermeulen, Nicolai Marquardt, Lora Oehlberg, and Saul Greenberg. 2018. Evaluation strategies for HCI toolkit research. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–17. <https://doi.org/10.1145/3173574.3173610>
- [237] Ho-Dong Lee, Dongwon Kim, Min-Chul Park, and Gwi-Tae Park. 2008. Augmented reality based vision system for network based mobile robot. In *Asia-Pacific Conference on Computer Human Interaction*. Springer, 123–130. https://doi.org/10.1007/978-3-540-70585-7_14
- [238] Ho-Dong Lee, Hyun-Gu Lee, Joo-Hyung Kim, Min-Chul Park, and Gwi-Tae Park. 2007. Human machine interface with augmented reality for the network based mobile robot. In *International Conference on Knowledge-Based and Intelligent Information and Engineering Systems*. Springer, 57–64. https://doi.org/10.1007/978-3-540-74829-8_8
- [239] Joo-Haeng Lee, Junho Kim, and Hyun Kim. 2011. A note on hybrid control of robotic spatial augmented reality. In *2011 8th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI)*. IEEE, 621–626. <https://doi.org/10.1109/URAI.2011.6145895>
- [240] Jae Young Lee, Jong-Wook Lee, Teressa Talluri, Amarnathvarma Angani, and Jeong Bea Lee. 2020. Realization of Robot Fish with 3D Hologram Fish using Augmented Reality. In *2020 IEEE 2nd International Conference on Architecture, Construction, Environment and Hydraulics (ICACEH)*. IEEE, 102–104. <https://doi.org/10.1109/icaceh51803.2020.9366226>
- [241] Kevin Lee, Christopher Reardon, and Jonathan Fink. 2018. Augmented Reality in Human-Robot Cooperative Search. In *2018 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*. IEEE, 1–1. <https://doi.org/10.1109/ssrr.2018.8468659>
- [242] Myungho Lee, Nahal Norouzi, Gerd Bruder, Pamela J Wisniewski, and Gregory F Welch. 2018. The physical-virtual table: exploring the effects of a virtual human's physical influence on social interaction. In *Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology*. 1–11. <https://doi.org/10.1145/3281505.3281533>
- [243] Daniel Leithinger, Sean Follmer, Alex Olwal, Samuel Luescher, Akimitsu Hogge, Jinha Lee, and Hiroshi Ishii. 2013. Sublimate: state-changing virtual and physical rendering to augment interaction with shape displays. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 1441–1450. <https://doi.org/10.1145/2470654.2466191>
- [244] Daniel Leithinger and Hiroshi Ishii. 2010. Relief: a scalable actuated shape display. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction*. 221–222. <https://doi.org/10.1145/1709886.1709928>
- [245] Daniel Leithinger, David Lakatos, Anthony DeVincenzi, Matthew Blackshaw, and Hiroshi Ishii. 2011. Direct and gestural interaction with relief: a 2.5 D shape display. In *Proceedings of the 24th annual ACM symposium on User interface software and technology*. 541–548. <https://doi.org/10.1145/2047196.2047268>
- [246] Jakob Leitner, Michael Haller, Kyungdahn Yun, Woontack Woo, Maki Sugimoto, Masahiko Inami, Adrian David Cheok, and HD Been-Lirn. 2010. Physical interfaces for tabletop games. *Computers in Entertainment (CIE)* 7, 4 (2010), 1–21. <https://doi.org/10.1145/1658866.1658880>
- [247] Germán Leiva, Cuong Nguyen, Rubaiat Habib Kazi, and Paul Asente. 2020. Pronto: Rapid augmented reality video prototyping using sketches and enactment. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13. <https://doi.org/10.1145/3313831.3376160>
- [248] Alexander Lenhardt and Helge Ritter. 2010. An augmented-reality based brain-computer interface for robot control. In *International Conference on Neural Information Processing*. Springer, 58–65. https://doi.org/10.1007/978-3-642-17534-3_8
- [249] Francisco J Lera, Víctor Rodríguez, Carlos Rodríguez, and Vicente Matellán. 2014. Augmented reality in robotic assistance for the elderly. In *International technology robotics applications*. Springer, 3–11. https://doi.org/10.1007/978-3-319-02332-8_1
- [250] Mirna Lerotic, Adrian J Chung, George Mylonas, and Guang-Zhong Yang. 2007. Pq-space based non-photorealistic rendering for augmented reality. In *International Conference on Medical Image Computing and Computer-Assisted Intervention*. Springer, 102–109. https://doi.org/10.1007/978-3-540-75759-7_13
- [251] Florian Leutert, Christian Herrmann, and Klaus Schilling. 2013. A spatial augmented reality system for intuitive display of robotic data. In *2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 179–180. <https://doi.org/10.1109/hri.2013.6483560>
- [252] Florian Leutert and Klaus Schilling. 2012. Support of power plant telemaintenance with robots by augmented reality methods. In *2012 2nd International Conference on Applied Robotics for the Power Industry (CARPI)*. IEEE, 45–49. <https://doi.org/10.1109/carpi.2012.6473362>
- [253] Florian Leutert and Klaus Schilling. 2015. Augmented reality for telemaintenance and inspection in force-sensitive industrial robot applications. *IFAC-PapersOnLine* 48, 10 (2015), 153–158. <https://doi.org/10.1016/J.IFACOL.2015.08.124>
- [254] Chunxu Li, Ashraf Fahmy, and Johann Sienz. 2019. An augmented reality based human-robot interaction interface using Kalman filter sensor fusion. *Sensors* 19, 20 (2019), 4586. <https://doi.org/10.3390/s19204586>
- [255] Congyuan Liang, Chao Liu, Xiaofeng Liu, Long Cheng, and Chenguang Yang. 2019. Robot teleoperation system based on mixed reality. In *2019 IEEE 47th international conference on advanced robotics and mechatronics (ICARM)*. IEEE, 384–389. <https://doi.org/10.1109/icarm.2019.8834302>
- [256] Li Lin, Yunyong Shi, Andy Tan, Melia Bogari, Ming Zhu, Yu Xin, Haisong Xu, Yan Zhang, Le Xie, and Gang Chai. 2016. Mandibular angle split osteotomy based on a novel augmented reality navigation using specialized robot-assisted arms—A feasibility study. *Journal of Cranio-Maxillofacial Surgery* 44, 2 (2016), 215–223. <https://doi.org/10.1016/j.jcmcs.2015.10.024>
- [257] Natan Linder and Pattie Maes. 2010. LuminAR: portable robotic augmented reality interface design and prototype. In *Adjunct proceedings of the 23rd annual ACM symposium on User interface software and technology*. 395–396. <https://doi.org/10.1145/1866218.1866237>
- [258] David Lindlbauer, Jens Emil Grønbæk, Morten Birk, Kim Halskov, Marc Alexa, and Jörg Müller. 2016. Combining shape-changing interfaces and spatial augmented reality enables extended object appearance. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. 791–802. <https://doi.org/10.1145/2858036.2858457>
- [259] David Lindlbauer, Jörg Mueller, and Marc Alexa. 2017. Changing the appearance of real-world objects by modifying their surroundings. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. 3954–3965. <https://doi.org/10.1145/3025453.3025795>
- [260] David Lindlbauer and Andy D Wilson. 2018. Remixed reality: Manipulating space and time in augmented reality. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13. <https://doi.org/10.1145/3173574.3173703>
- [261] Ragavendra Lingamaneni, Thomas Kubitz, and Jürgen Scheible. 2017. DroneCAST: towards a programming toolkit for airborne multimedia display applications. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services*. 1–8. <https://doi.org/10.1145/3098279.3122128>

- [262] Hangxin Liu, Yaofang Zhang, Wenwen Si, Xu Xie, Yixin Zhu, and Song-Chun Zhu. 2018. Interactive robot knowledge patching using augmented reality. In *2018 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 1947–1954. <https://doi.org/10.1109/ICRA.2018.8462837>
- [263] Kexi Liu, Daisuke Sakamoto, Masahiko Inami, and Takeo Igarashi. 2011. Roboshop: multi-layered sketching interface for robot housework assignment and management. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 647–656. <https://doi.org/10.1145/1978942.1979035>
- [264] Wen P Liu, Jeremy D Richmon, Jonathan M Sorger, Mahdi Azizian, and Russell H Taylor. 2015. Augmented reality and cone beam CT guidance for transoral robotic surgery. *Journal of robotic surgery* 9, 3 (2015), 223–233. <https://doi.org/10.1007/s11701-015-0520-5>
- [265] Yuzhou Liu, Georg Novotny, Nikita Smirnov, Walter Morales-Alvarez, and Cristina Olaverri-Monreal. 2020. Mobile Delivery Robots: Mixed Reality-Based Simulation Relying on ROS and Unity 3D. In *2020 IEEE Intelligent Vehicles Symposium (IV)*. IEEE, 15–20. <https://doi.org/10.1109/IV47402.2020.9304701>
- [266] Salvatore Livatino, Filippo Banno, and Giovanni Muscato. 2011. 3-D integration of robot vision and laser data with semiautomatic calibration in augmented reality stereoscopic visual interface. *IEEE Transactions on Industrial Informatics* 8, 1 (2011), 69–77. <https://doi.org/10.1109/tti.2011.2174062>
- [267] Salvatore Livatino, Dario C Guastella, Giovanni Muscato, Vincenzo Rinaldi, Luciano Cantelli, Carmelo D Melita, Alessandro Caniglia, Riccardo Mazza, and Gianluca Padula. 2021. Intuitive robot teleoperation through multi-sensor informed mixed reality visual aids. *IEEE Access* 9 (2021), 25795–25808. <https://doi.org/10.1109/access.2021.3057808>
- [268] Salvatore Livatino, Giovanni Muscato, Filippo Banno, Davide De Tommaso, and Marco Macaluso. 2010. Video and laser based augmented reality stereoscopic viewing for mobile robot teleoperation. *IFAC Proceedings Volumes* 43, 23 (2010), 161–168. <https://doi.org/10.3182/20101005-4-RO-2018.00049>
- [269] Salvatore Livatino, Giovanni Muscato, Davide De Tommaso, and Marco Macaluso. 2010. Augmented reality stereoscopic visualization for intuitive robot teleguiding. In *2010 IEEE International Symposium on Industrial Electronics*. IEEE, 2828–2833. <https://doi.org/10.1109/ISIE.2010.5636955>
- [270] Matthew B Luebers, Connor Brooks, Minjae John Kim, Daniel Szafir, and Bradley Hayes. 2019. Augmented reality interface for constrained learning from demonstration. In *Proceedings of the 2nd International Workshop on Virtual, Augmented, and Mixed Reality for HRI (VAM-HRI)*.
- [271] Dario Luipers and Anja Richert. 2021. Concept of an Intuitive Human-Robot-Collaboration via Motion Tracking and Augmented Reality. In *2021 IEEE International Conference on Artificial Intelligence and Computer Applications (ICAICA)*. IEEE, 423–427. <https://doi.org/10.1109/icaica52286.2021.9498091>
- [272] Maria Luce Lupetti. 2016. Designing playful HRI: Acceptability of robots in everyday life through play. In *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 631–632. <https://doi.org/10.1109/hri.2016.7451891>
- [273] Maria Luce Lupetti, Giovanni Piumatti, Claudio Germak, and Fabrizio Lamberti. 2018. Design and Evaluation of a Mixed-Reality Playground for Child-Robot Games. *Multimodal Technologies and Interaction* 2, 4 (2018), 69. <https://doi.org/10.3390/mti2040069>
- [274] Andreas Luxenburger, Jonas Mohr, Torsten Spieldennner, Dieter Merkel, Fabio Espinosa, Tim Schwartz, Florian Reinicke, Julian Ahlers, and Markus Stoyke. 2019. Augmented reality for human-robot cooperation in aircraft assembly. In *2019 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*. IEEE, 263–2633. <https://doi.org/10.1109/AIVR46125.2019.00061>
- [275] Stéphane Magnenat, Morderchai Ben-Ari, Severin Klinger, and Robert W Sumner. 2015. Enhancing robot programming with visual feedback and augmented reality. In *Proceedings of the 2015 ACM conference on innovation and technology in computer science education*. 153–158. <https://doi.org/10.1145/2729094.2742585>
- [276] Karthik Mahadevan, Elaheh Sanoubari, Sowmya Somanath, James E Young, and Ehud Sharlin. 2019. AV-Pedestrian interaction design using a pedestrian mixed traffic simulator. In *Proceedings of the 2019 on designing interactive systems conference*. 475–486. <https://doi.org/10.1145/3322276.3322328>
- [277] Karthik Mahadevan, Mauricio Sousa, Anthony Tang, and Tovi Grossman. 2021. “Grip-that-there”: An Investigation of Explicit and Implicit Task Allocation Techniques for Human-Robot Collaboration. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–14. <https://doi.org/10.1145/3411764.3445355>
- [278] Kartik Mahajan, Thomas Groechel, Roxanna Pakkar, Julia Cordero, Haemin Lee, and Maja J Matarić. 2020. Adapting Usability Metrics for a Socially Assistive, Kinesthetic, Mixed Reality Robot Tutoring Environment. In *International Conference on Social Robotics*. Springer, 381–391. https://doi.org/10.1007/978-3-030-62056-1_32
- [279] Madij Mardi, Malik Mallem, Laredj Benchikh, and Samir Otmane. 2013. An evaluation of camera pose methods for an augmented reality system: Application to teaching industrial robots. In *Transactions on Computational Science XVII*. Springer, 3–30. https://doi.org/10.1007/978-3-642-35840-1_1
- [280] Jim Mainprice, Emrah Akin Sisbot, Thierry Siméon, and Rachid Alami. 2010. Planning safe and legible hand-over motions for human-robot interaction. In *IARP/IEEE-RAS/EURON workshop on technical challenges for dependable robots in human environments*.
- [281] Zhanai Makhataeva and Huseyin Atakan Varol. 2020. Augmented reality for robotics: a review. *Robotics* 9, 2 (2020), 21. <https://doi.org/10.3390/robotics9020021>
- [282] Zhanai Makhataeva, Altay Zhakatayev, and Huseyin Atakan Varol. 2019. Safety Aura Visualization for Variable Impedance Actuated Robots. In *2019 IEEE/SICE International Symposium on System Integration (SII)*. IEEE, 805–810. <https://doi.org/10.1109/SII.2019.8700332>
- [283] Sotiris Makris, Panagiotis Karagiannis, Spyridon Koukas, and Aleksandros Stereos Matthaiakis. 2016. Augmented reality system for operator support in human–robot collaborative assembly. *CIRP Annals* 65, 1 (2016), 61–64. <https://doi.org/10.1016/J.CIRP.2016.04.038>
- [284] Ehsan Malayjerdi, Mahdi Yaghoobi, and Mohammad Kardan. 2017. Mobile robot navigation based on fuzzy cognitive map optimized with grey wolf optimization algorithm used in augmented reality. In *2017 5th RSI International Conference on Robotics and Mechatronics (ICRoM)*. IEEE, 211–218. <https://doi.org/10.1109/icrom.2017.8466169>
- [285] Ivo Malý, David Sedláček, and Paulo Leitao. 2016. Augmented reality experiments with industrial robot in industry 4.0 environment. In *2016 IEEE 14th international conference on industrial informatics (INDIN)*. IEEE, 176–181. <https://doi.org/10.1109/INDIN.2016.7819154>
- [286] Raúl Marín and Pedro J Sanz. 2002. Augmented reality to teleoperate a robot through the Web. *IFAC Proceedings Volumes* 35, 1 (2002), 161–165. <https://doi.org/10.3182/20020721-6-ES-1901.00933>
- [287] Andrés Martín-Barrio, Juan Jesús Roldán-Gómez, Iván Rodríguez, Jaime Del Cerro, and Antonio Barrientos. 2020. Design of a Hyper-Redundant Robot and Teleoperation Using Mixed Reality for Inspection Tasks. *Sensors* 20, 8 (2020), 2181. <https://doi.org/10.3390/s20082181>
- [288] Zdeněk Materna, Michal Kapinus, Vítězslav Beran, Pavel Smrž, Manuel Giuliani, Nicole Mirlig, Susanne Stadler, Gerald Stollnberger, and Manfred Tscheligi. 2017. Using persona, scenario, and use case to develop a human–robot augmented reality collaborative workspace. In *Proceedings of the Companion of the 2017 ACM/IEEE International Conference on Human–Robot Interaction*. 201–202. <https://doi.org/10.1145/3029798.3038366>
- [289] Zdeněk Materna, Michal Kapinus, Vítězslav Beran, Pavel Smrž, and Pavel Zemčík. 2018. Interactive spatial augmented reality in collaborative robot programming: User experience evaluation. In *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 80–87. <https://doi.org/10.1109/roman.2018.8525562>
- [290] Florin Octavian Matu, Mikkel Thøgersen, Bo Galsgaard, Martin Møller Jensen, and Martin Kraus. 2014. Stereoscopic augmented reality system for supervised training on minimal invasive surgery robots. In *Proceedings of the 2014 Virtual Reality International Conference*. 1–4. <https://doi.org/10.1145/2617841.2620722>
- [291] William A McNeely. 1993. Robotic graphics: new approach to force feedback for virtual reality. In *Proceedings of IEEE Virtual Reality Annual International Symposium*. IEEE, 336–341. <https://doi.org/10.1109/VRAIS.1993.380761>
- [292] George Michalos, Panagiotis Karagiannis, Sotiris Makris, Önder Tokçalar, and George Chrysoulouris. 2016. Augmented reality (AR) applications for supporting human–robot interactive cooperation. *Procedia CIRP* 41 (2016), 370–375. <https://doi.org/10.1016/J.PROCIR.2015.12.005>
- [293] Paul Milgram and Fumio Kishino. 1994. A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems* 77, 12 (1994), 1321–1329.
- [294] Paul Milgram, Shumin Zhai, David Drascic, and Julius Grodski. 1993. Applications of augmented reality for human–robot communication. In *Proceedings of 1993 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS’93)*, Vol. 3. IEEE, 1467–1472. <https://doi.org/10.1109/IROS.1993.583833>
- [295] Omid Moharer and Ahmad B Rad. 2011. Autonomous humanoid robot navigation using augmented reality technique. In *2011 IEEE International Conference on Mechatronics*. IEEE, 463–468. <https://doi.org/10.1109/imech.2011.5971330>
- [296] Nicolas Mollet, Ryad Chellali, and Luca Brayda. 2009. Virtual and augmented reality tools for teleoperation: improving distant immersion and perception. In *Transactions on edutainment II*. Springer, 135–159. https://doi.org/10.1007/978-3-642-03270-7_10
- [297] William Montalvo, Pablo Bonilla-Vasconez, Santiago Altamirano, Carlos A Garcia, and Marcelo V Garcia. 2020. Industrial Control Robot Based on Augmented Reality and IoT Protocol. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*. Springer, 345–363. https://doi.org/10.1007/978-3-030-58468-9_25
- [298] Rafael Morales, Asier Marzo, Sriram Subramanian, and Diego Martínez. 2019. LeviProps: Animating levitated optimized fabric structures using holographic acoustic tweezers. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*. 651–661. <https://doi.org/10.1145/3332165.3347882>
- [299] Stephen A Morin, Robert F Shepherd, Sen Wai Kwok, Adam A Stokes, Alex Nemiroski, and George M Whitesides. 2012. Camouflage and display for soft machines. *Science* 337, 6096 (2012), 828–832. <https://doi.org/10.1126/science.1222149>

- [300] Kohei Morita, Takefumi Hiraki, Haruka Matsukura, Daisuke Iwai, and Kosuke Sato. 2020. Extension of Projection Area using Head Orientation in Projected Virtual Hand Interface for Wheelchair Users. In *2020 59th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE)*. IEEE, 421–426. <https://doi.org/10.23919/SICE48898.2020.9240271>
- [301] D Mourtzis, G Synodinos, J Angelopoulos, and N Panopoulos. 2020. An augmented reality application for robotic cell customization. *Procedia CIRP* 90 (2020), 654–659. <https://doi.org/10.1016/j.procir.2020.02.135>
- [302] Dimitris Mourtzis, Vasilios Zogopoulos, and E Vlachou. 2017. Augmented reality application to support remote maintenance as a service in the robotics industry. *Procedia Cirp* 63 (2017), 46–51. <https://doi.org/10.1016/j.procir.2017.03.154>
- [303] Fabian Mueller, Christian Deuerlein, and Michael Koch. 2019. Intuitive welding robot programming via motion capture and augmented reality. *IFAC-PapersOnLine* 52, 10 (2019), 294–299. <https://doi.org/10.1016/j.ifacol.2019.10.045>
- [304] Stefanie Mueller, Pedro Lopez, and Patrick Baudisch. 2012. Interactive construction: interactive fabrication of functional mechanical devices. In *Proceedings of the 25th annual ACM symposium on User interface software and technology*, 599–606. <https://doi.org/10.1145/2380116.2380191>
- [305] Faizan Muhammad, Amel Hassan, Andre Cleaver, and Jivko Sinapov. 2019. Creating a shared reality with robots. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 614–615. <https://doi.org/10.1109/HRI.2019.8673191>
- [306] Alex Murphy and Alan G Millard. 2020. Prototyping Sensors and Actuators for Robot Swarms in Mixed Reality. In *Annual Conference Towards Autonomous Robotic Systems*. Springer, 377–386. https://doi.org/10.1007/978-3-030-63486-5_39
- [307] B MUTLU. [n.d.]. Modeling and Evaluation of Human-like Gaze Behavior. *Humanoids'06* ([n. d.]). <https://doi.org/10.1109/ICHR.2006.321322>
- [308] Ken Nakagaki, Luke Vink, Jared Counts, Daniel Windham, Daniel Leithinger, Sean Follmer, and Hiroshi Ishii. 2016. Materiable: Rendering dynamic material properties in response to direct physical touch with shape changing interfaces. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 2764–2772. <https://doi.org/10.1145/2858036.2858104>
- [309] Nassir Navab, Christoph Hennersperger, Benjamin Frisch, and Bernhard Fürst. 2016. Personalized, relevance-based multimodal robotic imaging and augmented reality for computer assisted interventions. , 64–71 pages. <https://doi.org/10.1016/j.media.2016.06.021>
- [310] Aditya Nawab, Keshav Chintamani, Darin Ellis, Gregory Auner, and Abhilash Pandya. 2007. Joystick mapped augmented reality cues for end-effector controlled tele-operated robots. In *2007 IEEE Virtual Reality Conference*. IEEE, 263–266. <https://doi.org/10.1109/vr.2007.352496>
- [311] Michael Nebeling, Janet Nebeling, Ao Yu, and Rob Rumble. 2018. Protoar: Rapid physical-digital prototyping of mobile augmented reality applications. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–12. <https://doi.org/10.1145/3173574.3173927>
- [312] Chuen Leong Ng, Tech Chew Ng, Thi Anh Ngoc Nguyen, Guilin Yang, and Wenjie Chen. 2010. Intuitive robot tool path teaching using laser and camera in augmented reality environment. In *2010 11th International Conference on Control Automation Robotics & Vision*. IEEE, 114–119. <https://doi.org/10.1109/icarv.2010.5707399>
- [313] D Ni, AWW Yew, SK Ong, and AYC Nee. 2017. Haptic and visual augmented reality interface for programming welding robots. *Advances in Manufacturing* 5, 3 (2017), 191–198. <https://doi.org/10.1007/s40436-017-0184-7>
- [314] Sivapong Nilwong and Genci Capi. 2020. Outdoor Robot Navigation System using Game-Based DQN and Augmented Reality. In *2020 17th International Conference on Ubiquitous Robots (UR)*. IEEE, 74–80. <https://doi.org/10.1109/ur49135.2020.9144838>
- [315] Koichi Nishiwaki, Kazuhiko Kobayashi, Shinji Uchiyama, Hiroyuki Yamamoto, and Satoshi Kagami. 2008. Mixed reality environment for autonomous robot development. In *2008 IEEE International Conference on Robotics and Automation*. IEEE, 2211–2212. <https://doi.org/10.1109/ROBOT.2008.4545358>
- [316] Diana Nowacka, Karim Ladha, Nils Y Hammerla, Daniel Jackson, Cassim Ladha, Enrico Rukzio, and Patrick Olivier. 2013. Touchbugs: Actuated tangibles on multi-touch tables. In *Proceedings of the SIGCHI conference on human factors in computing systems*, 759–762. <https://doi.org/10.1145/2470654.2470761>
- [317] Hiroki Nozaki. 2014. Flying display: movable display pairing projector and screen in the air. In *CHI'14 Extended Abstracts on Human Factors in Computing Systems*. 909–914. <https://doi.org/10.1145/2559206.2579410>
- [318] R Nunez, JR Bandera, JM Perez-Lorenzo, and Francisco Sandoval. 2006. A human-robot interaction system for navigation supervision based on augmented reality. In *MELECON 2006-2006 IEEE Mediterranean Electrotechnical Conference*. IEEE, 441–444. <https://doi.org/10.1109/melcon.2006.1653133>
- [319] Cristina Nuzzi, Stefano Ghidini, Roberto Pagani, Simone Pasinetti, Gabriele Coffetti, and Giovanna Sansoni. 2020. Hands-Free: a robot augmented reality teleoperation system. In *2020 17th International Conference on Ubiquitous Robots (UR)*. IEEE, 617–624. <https://doi.org/10.1109/ur49135.2020.9144841>
- [320] Yoichi Ochiai and Keisuke Toyoshima. 2011. Homunculus: the vehicle as augmented clothes. In *Proceedings of the 2nd Augmented Human International Conference*. 1–4. <https://doi.org/10.1145/1959826.1959829>
- [321] Yusuke Okuno, Takayuki Kanda, Michita Imai, Hiroshi Ishiguro, and Norihiro Hagita. 2009. Providing route directions: design of robot's utterance, gesture, and timing. In *2009 4th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 53–60. <https://doi.org/10.1145/1514095.1514108>
- [322] Shayegan Omidshafiei, Ali-Akbar Agha-Mohammadi, Yu Fan Chen, Nazim Kermal Ure, Shih-Yuan Liu, Brett T Lopez, Rajeev Surati, Jonathan P How, and John Vian. 2016. Measurable augmented reality for prototyping cyberphysical systems: A robotics platform to aid the hardware prototyping and performance testing of algorithms. *IEEE Control Systems Magazine* 36, 6 (2016), 65–87. <https://doi.org/10.1109/mcs.2016.2602090>
- [323] SK Ong, AWW Yew, NK Thanigaivel, and AYC Nee. 2020. Augmented reality-assisted robot programming system for industrial applications. *Robotics and Computer-Integrated Manufacturing* 61 (2020), 101820. <https://doi.org/10.1016/J.RCIM.2019.101820>
- [324] Soh-Khim Ong, JWS Chong, and Andrew YC Nee. 2006. Methodologies for immersive robot programming in an augmented reality environment. In *Proceedings of the 4th international conference on computer graphics and interactive techniques in Australasia and Southeast Asia*. 237–244. <https://doi.org/10.1145/1174429.1174470>
- [325] Mikhail Ostanin and Alexandr Klimchik. 2018. Interactive robot programing using mixed reality. *IFAC-PapersOnLine* 51, 22 (2018), 50–55. <https://doi.org/10.1016/j.ifacol.2018.11.517>
- [326] Mikhail Ostanin, Stanislav Milkhe, Alexey Evlampiev, Valeria Skvortsova, and Alexandr Klimchik. 2020. Human-robot interaction for robotic manipulator programming in Mixed Reality. In *2020 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2805–2811. <https://doi.org/10.1109/ICRA40945.2020.9196965>
- [327] M Ostanin, R Yagfarov, and A Klimchik. 2019. Interactive Robots Control Using Mixed Reality. *IFAC-PapersOnLine* 52, 13 (2019), 695–700. <https://doi.org/10.1016/j.ifacol.2019.11.307>
- [328] Ayberk Özgür, Séverin Lemaignan, Wafa Johal, Maria Beltran, Manon Brio, Léa Pereyre, Francesco Mondada, and Pierre Dillenbourg. 2017. Cellulô: Versatile handheld robots for education. In *2017 12th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 119–127. <https://doi.org/10.1145/2909824.3020247>
- [329] Yun Suen Pai, Hwa Jen Yap, Siti Zawiah Md Dawal, S Ramesh, and Sin Ye Phoon. 2016. Virtual planning, control, and machining for a modular-based automated factory operation in an augmented reality environment. *Scientific reports* 6, 1 (2016), 1–19. <https://doi.org/10.1038/srep27380>
- [330] Yong Pan, Chengjun Chen, Dongnian Li, Zhengxu Zhao, and Jun Hong. 2021. Augmented reality-based robot teleoperation system using RGB-D imaging and attitude teaching device. *Robotics and Computer-Integrated Manufacturing* 71 (2021), 102167. <https://doi.org/10.1016/J.RCIM.2021.102167>
- [331] Gian Pangaro, Dan Maynes-Aminzade, and Hiroshi Ishii. 2002. The actuated workbench: computer-controlled actuation in tabletop tangible interfaces. In *Proceedings of the 15th annual ACM symposium on User interface software and technology*, 181–190. <https://doi.org/10.1145/571985.572011>
- [332] Christos Papachristos and Kostas Alexis. 2016. Augmented reality-enhanced structural inspection using aerial robots. In *2016 IEEE international symposium on intelligent control (ISIC)*. IEEE, 1–6. <https://doi.org/10.1109/ISIC.2016.7579983>
- [333] Peter Papcun, Jan Cabadaj, Erik Kajati, David Romero, Lenka Landryova, Jan Vasak, and Iveta Zolotova. 2019. Augmented Reality for Humans-Robots Interaction in Dynamic Slotting "Chaotic Storage" Smart Warehouses. In *IFIP International Conference on Advances in Production Management Systems*. Springer, 633–641. https://doi.org/10.1007/978-3-030-30000-5_77
- [334] Hyeshin Park, Yo-An Lim, Aslam Pervez, Beom-Chan Lee, Sang-Goog Lee, and Jeha Ryu. 2007. Teleoperation of a multi-purpose robot over the internet using augmented reality. In *2007 International Conference on Control, Automation and Systems*. IEEE, 2456–2461. <https://doi.org/10.1109/iccas.2007.4406776>
- [335] Jung Pil Park, Min Woo Park, and Soon Ki Jung. 2014. Qr-code based online robot augmented reality system for education. In *Proceedings of the 29th Annual ACM Symposium on Applied Computing*. 180–185. <https://doi.org/10.1145/2554850.2555038>
- [336] Kyeong-Beom Park, Sung Hy Choi, Jae Yeol Lee, Yalda Ghasemi, Mustafa Mohammed, and Heejin Jeong. 2021. Hands-Free Human-Robot Interaction Using Multimodal Gestures and Deep Learning in Wearable Mixed Reality. *IEEE Access* 9 (2021), 55448–55464. <https://doi.org/10.1109/access.2021.3071364>
- [337] Yoon Jung Park, Hyocheol Ro, and Tack-Don Han. 2019. Deep-ChildAR bot: educational activities and safety care augmented reality system with deep-learning for preschool. In *ACM SIGGRAPH 2019 Posters*. 1–2. <https://doi.org/10.1145/3306214.3338589>
- [338] Yoon Jung Park, Yoonsik Yang, Hyocheol Ro, JungHyun Byun, Seougooh Chae, and Tack-Don Han. 2018. Meet AR-bot: Meeting Anywhere, Anytime with Moveable Spatial AR Robot. In *Proceedings of the 26th ACM international conference on Multimedia*. 1242–1243. <https://doi.org/10.1145/3240508.3241390>
- [339] James Patten and Hiroshi Ishii. 2007. Mechanical constraints as computational constraints in tabletop tangible interfaces. In *Proceedings of the SIGCHI conference*

- on Human factors in computing systems*. 809–818. <https://doi.org/10.1145/1240624.1240746>
- [340] Esben Warming Pedersen and Kasper Hornbæk. 2011. Tangible bots: interaction with active tangibles in tabletop interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2975–2984. <https://doi.org/10.1145/1978942.1979384>
- [341] Huaihu Peng, Jimmy Briggs, Cheng-Yao Wang, Kevin Guo, Joseph Kider, Stefanie Mueller, Patrick Baudisch, and François Guimbretière. 2018. RoMA: Interactive fabrication with augmented reality and a robotic 3D printer. In *Proceedings of the 2018 CHI conference on human factors in computing systems*. 1–12. <https://doi.org/10.1145/3173574.3174153>
- [342] Lorenzo Pепpolonи, Filippo Brizzi, Emanuele Ruffaldi, and Carlo Alberto Avizzone. 2015. Augmented reality-aided tele-presence system for robot manipulation in industrial manufacturing. In *Proceedings of the 21st ACM Symposium on Virtual Reality Software and Technology*. 237–240. <https://doi.org/10.1145/2821592.2821620>
- [343] Nate Phillips, Brady Kruse, Farzana Alam Khan, J Edward Swan II, and Cindy L Bethel. 2020. A Robotic Augmented Reality Virtual Window for Law Enforcement Operations. In *International Conference on Human-Computer Interaction*. Springer, 591–610. https://doi.org/10.1007/978-3-030-49695-1_40
- [344] Luis Piardi, Vivian Cremer Kalempa, Marcelo Limeira, André Schneider de Oliveira, and Paulo Leitão. 2019. ARENA—augmented reality to enhanced experimentation in smart warehouses. *Sensors* 19, 19 (2019), 4308. <https://doi.org/10.3390/s19194308>
- [345] Carlo Pincioli, Mohamed S Talamali, Andreagiovanni Reina, James AR Marshall, and Vito Trianni. 2018. Simulating kilobots within argos: models and experimental validation. In *International Conference on Swarm Intelligence*. Springer, 176–187. https://doi.org/10.1007/978-3-030-00533-7_14
- [346] Giovanni Piumatti, Andrea Sanna, Marco Gaspardone, and Fabrizio Lamberti. 2017. Spatial augmented reality meets robots: Human-machine interaction in cloud-based projected gaming environments. In *2017 IEEE International Conference on Consumer Electronics (ICCE)*. IEEE, 176–179. <https://doi.org/10.1109/ICCE.2017.7789276>
- [347] Francesco Porpiglia, Enrico Checucci, Daniele Amparore, Matteo Manfredi, Federica Massa, Pietro Piazzolla, Diego Manfrin, Alberto Piana, Daniele Tota, Enrico Bollito, et al. 2019. Three-dimensional elastic augmented-reality robot-assisted radical prostatectomy using hyperaccuracy three-dimensional reconstruction technology: a step further in the identification of capsular involvement. *European urology* 76, 4 (2019), 505–514. <https://doi.org/10.1016/j.euro.2019.03.037>
- [348] Francesco Porpiglia, Enrico Checucci, Daniele Amparore, Federico Piramide, Gabriele Volpi, Stefano Granato, Paola Verri, Matteo Manfredi, Andrea Bellini, Pietro Piazzolla, et al. 2020. Three-dimensional augmented reality robot-assisted partial nephrectomy in case of complex tumours (PADUA \geq 10): a new intraoperative tool overcoming the ultrasound guidance. *European urology* 78, 2 (2020), 229–238. <https://doi.org/10.1016/j.euro.2019.11.024>
- [349] Ivan Poupyrev, Tatsushi Nashida, and Makoto Okabe. 2007. Actuation and tangible user interfaces: the Vaucanson duck, robots, and shape displays. In *Proceedings of the 1st international conference on Tangible and embedded interaction*. 205–212. <https://doi.org/10.1145/1226969.1227012>
- [350] F Gabriele Prattico, Alberto Cannavò, Junchao Chen, and Fabrizio Lamberti. 2019. User Perception of Robot's Role in Floor Projection-based Mixed-Reality Robotic Games. In *2019 IEEE 23rd International Symposium on Consumer Technologies (ISCT)*. IEEE, 76–81. <https://doi.org/10.1109/isce.2019.8901037>
- [351] Filippo Gabriele Prattico, Francisco Navarro Merino, and Fabrizio Lamberti. 2020. Is Learning by Teaching an Effective Approach in Mixed-Reality Robotic Training Systems?. In *International Conference on Intelligent Technologies for Interactive Entertainment*. Springer, 177–190. https://doi.org/10.1007/978-3-030-76426-5_12
- [352] David Puljiz, Franziska Krebs, Fabian Bosing, and Bjorn Hein. 2020. What the HoloLens Maps Is Your Workspace: Fast Mapping and Set-up of Robot Cells via Head Mounted Displays and Augmented Reality. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 11445–11451. <https://doi.org/10.1109/iros45743.2020.9340879>
- [353] Isabel PS Qamar, Rainer Groh, David Holman, and Anne Roudaut. 2018. HCI meets material science: A literature review of morphing materials for the design of shape-changing interfaces. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–23. <https://doi.org/10.1145/3173574.3173948>
- [354] Long Qian, Anton Deguet, Zerui Wang, Yun-Hui Liu, and Peter Kazanzides. 2019. Augmented reality assisted instrument insertion and tool manipulation for the first assistant in robotic surgery. In *2019 International Conference on Robotics and Automation (ICRA)*. IEEE, 5173–5179. <https://doi.org/10.1109/ICRA.2019.8794263>
- [355] Long Qian, Chengzhi Song, Yiwei Jiang, Qi Luo, Xin Ma, Philip Waiyan Chiu, Zheng Li, and Peter Kazanzides. 2020. FlexiVision: Teleporting the Surgeon's Eyes via Robotic Flexible Endoscope and Head-Mounted Display. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 3281–3287. <https://doi.org/10.1109/IROS45743.2020.9340716>
- [356] Long Qian, Jie Ying Wu, Simon P DiMaio, Nassir Navab, and Peter Kazanzides. 2019. A review of augmented reality in robotic-assisted surgery. *IEEE Transactions on Medical Robotics and Bionics* 2, 1 (2019), 1–16. <https://doi.org/10.1109/tmrb.2019.2957061>
- [357] Shuwen Qiu, Hangxin Liu, Zeyu Zhang, Yixin Zhu, and Song-Chun Zhu. 2020. Human-Robot Interaction in a Shared Augmented Reality Workspace. In *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 11413–11418. <https://doi.org/10.1109/iros45743.2020.9340781>
- [358] Camilo Perez Quintero, Sarah Li, Matthew KXJ Pan, Wesley P Chan, HF Machiel Van der Loos, and Elizabeth Croft. 2018. Robot programming through augmented trajectories in augmented reality. In *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 1838–1844. <https://doi.org/10.1109/IROS.2018.8593700>
- [359] Majken K Rasmussen, Esben W Pedersen, Marianne G Petersen, and Kasper Hornbæk. 2012. Shape-changing interfaces: a review of the design space and open research questions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 735–744. <https://doi.org/10.1145/2207676.2207781>
- [360] Christopher Reardon, Jason Gregory, Carlos Nieto-Granda, and John G Rogers. 2020. Enabling Situational Awareness via Augmented Reality of Autonomous Robot-Based Environmental Change Detection. In *International Conference on Human-Computer Interaction*. Springer, 611–628. https://doi.org/10.1007/978-3-030-49695-1_41
- [361] Christopher Reardon, Kevin Lee, and Jonathan Fink. 2018. Come see this! augmented reality to enable human-robot cooperative search. In *2018 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*. IEEE, 1–7. <https://doi.org/10.1109/SSRR.2018.8468622>
- [362] Christopher Reardon, Kevin Lee, John G Rogers, and Jonathan Fink. 2019. Augmented reality for human-robot teaming in field environments. In *International Conference on Human-Computer Interaction*. Springer, 79–92. https://doi.org/10.1007/978-3-030-21565-1_6
- [363] Christopher Reardon, Kevin Lee, John G Rogers, and Jonathan Fink. 2019. Communicating via augmented reality for human-robot teaming in field environments. In *2019 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*. IEEE, 94–101. <https://doi.org/10.1109/SSRR.2019.8848971>
- [364] Andreagiovanni Reina, Mattia Salvaro, Gianpiero Francesca, Lorenzo Garattoni, Carlo Pincioli, Marco Dorigo, and Mauro Birattari. 2015. Augmented reality for robots: virtual sensing technology applied to a swarm of e-pecks. In *2015 NASA/ESA Conference on Adaptive Hardware and Systems (AHS)*. IEEE, 1–6. <https://doi.org/10.1109/ahs.2015.7231154>
- [365] Ying Ren and Jiro Tanaka. 2019. Augmented Reality Based Actuated Monitor Manipulation from Dual Point of View. In *International Conference on Human-Computer Interaction*. Springer, 93–107. https://doi.org/10.1007/978-3-030-21565-1_7
- [366] Patrick Renner, Florian Lier, Felix Friese, Thies Pfeiffer, and Sven Wachsmuth. 2018. Facilitating HRI by mixed reality techniques. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. 215–216. <https://doi.org/10.1145/3173386.3177032>
- [367] Patrick Renner, Florian Lier, Felix Friese, Thies Pfeiffer, and Sven Wachsmuth. 2018. Wysiwid: What you see is what I do. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. 382–382. <https://doi.org/10.1145/3173386.3177533>
- [368] Hyocheol Ro, Jung-Hyun Byun, Inhwan Kim, Yoon Jung Park, Kyuri Kim, and Tack-Don Han. 2019. Projection-based augmented reality robot prototype with human-awareness. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 598–599. <https://doi.org/10.1109/HRI.2019.8673173>
- [369] David Robert and Cynthia Breazeal. 2012. Blended reality characters. In *Proceedings of the seventh annual ACM/IEEE international conference on Human-Robot Interaction*. 359–366. <https://doi.org/10.1145/2157689.2157810>
- [370] David Robert, Ryan Wistort, Jesse Gray, and Cynthia Breazeal. 2010. Exploring mixed reality robot gaming. In *Proceedings of the fifth international conference on tangible, embedded, and embodied interaction*. 125–128. <https://doi.org/10.1145/1935701.1935726>
- [371] Nancy Rodriguez, Luis Jose Pulido, and Jean-Pierre Jessel. 2004. Enhancing a telerobotics Java tool with augmented reality. In *International Symposium and School on Advances Distributed Systems*. Springer, 9–18. https://doi.org/10.1007/978-3-540-25958-9_2
- [372] Eric Rosen, David Whitney, Elizabeth Phillips, Gary Chien, James Tompkin, George Konidaris, and Stefan Tellex. 2020. Communicating robot arm motion intent through mixed reality head-mounted displays. In *Robotics research*. Springer, 301–316. https://doi.org/10.1007/978-3-030-28619-4_26
- [373] Alexandros Rotsidis, Andreas Theodorou, Joanna J Bryson, and Robert H Wortham. 2019. Improving robot transparency: An investigation with mobile augmented reality. In *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 1–8. <https://doi.org/10.1109/ro-man46459.2019.8956390>
- [374] Anne Roudaut, Abhijit Karnik, Markus Löchtefeld, and Sriram Subramanian. 2013. Morphes: toward high" shape resolution" in self-actuated flexible mobile devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing*

- Systems*. 593–602. <https://doi.org/10.1145/2470654.2470738>
- [375] Dávid Rozenberszki and Gábor Sörös. 2021. Towards Universal User Interfaces for Mobile Robots. In *Augmented Humans Conference 2021*. 274–276. <https://doi.org/10.1145/3458709.3458996>
- [376] Emanuele Ruffaldi, Filippo Brizzi, Franco Tecchia, and Sandro Bacinelli. 2016. Third point of view augmented reality for robot intentions visualization. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*. Springer, 471–478. https://doi.org/10.1007/978-3-319-40621-3_35
- [377] JJ Ruiz, A Viguria, JR Martinez-de Dios, and A Ollero. 2015. Immersive displays for building spatial knowledge in multi-UAV operations. In *2015 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE, 1043–1048. <https://doi.org/10.1109/icuas.2015.7152395>
- [378] Golnoosh Samei, Keith Tsang, Claudia Kesch, Julio Lobo, Soheil Hor, Omid Moharer, Silvia Chang, S Larry Goldenberg, Peter C Black, and Septimiu Salcudean. 2020. A partial augmented reality system with live ultrasound and registered preoperative MRI for guiding robot-assisted radical prostatectomy. *Medical image analysis* 60 (2020), 101588. <https://doi.org/10.1016/j.media.2019.101588>
- [379] Yasumitsu Sarai and Yusuke Maeda. 2017. Robot programming for manipulators through volume sweeping and augmented reality. In *2017 13th ieee conference on automation science and engineering (case)*. IEEE, 302–307. <https://doi.org/10.1109/COASE.2017.8256120>
- [380] Markus Sauer, Frauke Driewer, Manuel Göllnitz, and Klaus Schilling. 2007. Potential and challenges of stereo augmented reality for mobile robot teleoperation. *IFAC Proceedings Volumes* 40, 16 (2007), 183–188. <https://doi.org/10.3182/20070904-3-KR-2922.00032>
- [381] Markus Sauer, Martin Hess, and Klaus Schilling. 2009. Towards a predictive mixed reality user interface for mobile robot teleoperation. *IFAC Proceedings Volumes* 42, 22 (2009), 91–96. <https://doi.org/10.3182/20091006-3-US-4006.00016>
- [382] Jürgen Scheible, Achim Hoth, Julian Saal, and Haifeng Su. 2013. Displayrone: a flying robot based interactive display. In *Proceedings of the 2nd ACM International Symposium on Pervasive Displays*. 49–54. <https://doi.org/10.1145/2491568.2491580>
- [383] Riccardo Schiavina, Lorenzo Bianchi, Francesco Chessa, Umberto Barbaresi, Laura Cercenelli, Simone Lodi, Caterina Gaudiano, Barbara Bortolani, Andrea Angiolini, Federico Mineo Bianchi, et al. 2021. Augmented reality to guide selective clamping and tumor dissection during robot-assisted partial nephrectomy: a preliminary experience. *Clinical genitourinary cancer* 19, 3 (2021), e149–e155. <https://doi.org/10.1016/j.clgc.2020.09.005>
- [384] Riccardo Schiavina, Lorenzo Bianchi, Simone Lodi, Laura Cercenelli, Francesco Chessa, Barbara Bortolani, Caterina Gaudiano, Carlo Casablanca, Matteo Droghetti, Angelo Porreca, et al. 2021. Real-time augmented reality three-dimensional guided robotic radical prostatectomy: preliminary experience and evaluation of the impact on surgical planning. *European urology focus* 7, 6 (2021), 1260–1267. <https://doi.org/10.1016/j.euf.2020.08.004>
- [385] Jan Schmitt, Andreas Hillenbrand, Philipp Kranz, and Tobias Kaupp. 2021. Assisted Human-Robot-Interaction for Industrial Assembly: Application of Spatial Augmented Reality (SAR) for Collaborative Assembly Tasks. In *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*. 52–56. <https://doi.org/10.1145/3434074.3447127>
- [386] Julian Seifert, Sebastian Boring, Christian Winkler, Florian Schaub, Fabian Schwab, Steffen Herrdum, Fabian Maier, Daniel Mayer, and Enrico Rukzio. 2014. Hover Pad: interacting with autonomous and self-actuated displays in space. In *Proceedings of the 27th annual ACM symposium on User interface software and technology*. 139–147. <https://doi.org/10.1145/2642918.2647385>
- [387] Ronny Seiger, Mandy Korzetz, Maria Gohlke, and Uwe Aßmann. 2017. Mixed reality cyber-physical systems control and workflow composition. In *Proceedings of the 16th International Conference on Mobile and Ubiquitous Multimedia*. 495–500. <https://doi.org/10.1145/3152832.3157808>
- [388] Martin Sletecký, Jan Faigl, and Milan Rollo. 2019. Analysis of using mixed reality simulations for incremental development of multi-uav systems. *Journal of Intelligent & Robotic Systems* 95, 1 (2019), 211–227. <https://doi.org/10.1007/S10846-018-0875-8>
- [389] Atsushi Sengiku, Masanao Koeda, Atsuro Sawada, Jin Kono, Naoki Terada, Toshiharu Yamasaki, Kiminori Mizushima, Takahiro Kunii, Katsuhiiko Onishi, Hiroshi Noborio, et al. 2017. Augmented reality navigation system for robot-assisted laparoscopic partial nephrectomy. In *International Conference of Design, User Experience, and Usability*. Springer, 575–584. https://doi.org/10.1007/978-3-319-58637-3_45
- [390] Rossitza Setchi, Maryam Banitalebi Dehkordi, and Juwairiya Siraj Khan. 2020. Explainable Robotics in Human-Robot Interactions. *Procedia Computer Science* 176 (2020), 3057–3066. <https://doi.org/10.1016/j.procs.2020.09.198>
- [391] Nikitas M Sgouros and Sophia Koussidou. 2001. Generation and implementation of mixed-reality, narrative performances involving robotic actors. In *International Conference on Virtual Storytelling*. Springer, 69–78. https://doi.org/10.1007/3-540-45420-9_9
- [392] Dylan Shah, Bilage Yang, Sam Kriegman, Michael Levin, Josh Bongard, and Rebecca Kramer-Bottiglio. 2021. Shape changing robots: bioinspiration, simulation, and physical realization. *Advanced Materials* 33, 19 (2021), 2002882. <https://doi.org/10.1002/adma.202002882>
- [393] Shyang Shao, Satoshi Muramatsu, Katsuhiiko Inagaki, Daisuke Chugo, Syo Yokota, and Hiroshi Hashimoto. 2019. Development of robot design evaluating system using Augmented Reality for affinity robots. In *2019 IEEE 17th International Conference on Industrial Informatics (INDIN)*, Vol. 1. IEEE, 815–820. <https://doi.org/10.1109/indin41052.2019.897205>
- [394] Jun Shen, Nabil Zemiti, Christophe Taoum, Guillaume Aiche, Jean-Louis Dilenseger, Philippe Rouanet, and Philippe Poignet. 2020. Transrectal ultrasound sound image-based real-time augmented reality guidance in robot-assisted laparoscopic rectal surgery: a proof-of-concept study. *International journal of computer assisted radiology and surgery* 15, 3 (2020), 531–543. <https://doi.org/10.1007/s11548-019-02100-2>
- [395] Noriyoshi Shimizu, Maki Sugimoto, Dairoku Sekiguchi, Shoichi Hasegawa, and Masahiko Inami. 2008. Mixed reality robotic user interface: virtual kinematics to enhance robot motion. In *Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology*. 166–169. <https://doi.org/10.1145/1501750.1501789>
- [396] Elena Sibirtseva, Ali Ghadirzadeh, Iolanda Leite, Märten Björkman, and Daniela Krägic. 2019. Exploring temporal dependencies in multimodal referring expressions with mixed reality. In *International Conference on Human-Computer Interaction*. Springer, 108–123. https://doi.org/10.1007/978-3-030-21565-1_8
- [397] Dietmar Siegle, Dieter Steiner, Andrea Giusti, Michael Riedl, and Dominik T Matt. 2021. Optimizing Collaborative Robotic Workspaces in Industry by Applying Mixed Reality. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics*. Springer, 544–559. https://doi.org/10.1007/978-3-030-87595-4_40
- [398] Torsten Sebastian Sievers, Bianca Schmitt, Patrick Rückert, Maren Petersen, and Kirsten Tracht. 2020. Concept of a Mixed-Reality Learning Environment for Collaborative Robotics. *Procedia Manufacturing* 45 (2020), 19–24. <https://doi.org/10.1016/j.promfg.2020.04.034>
- [399] David Sirkin, Brian Mok, Stephen Yang, and Wendy Ju. 2015. Mechanical ottoman: how robotic furniture offers and withdraws support. In *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction*. 11–18. <https://doi.org/10.1145/2696454.2696461>
- [400] Enrico Sita, Matthew Studley, Farid Dailami, Anthony Pipe, and Trygve Thomsen. 2017. Towards multimodal interactions: robot jogging in mixed reality. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology*. 1–2. <https://doi.org/10.1145/3139131.3141200>
- [401] Alexa F Siu, Shenli Yuan, Hieu Pham, Eric Gonzalez, Lawrence H Kim, Mathieu Le Goc, and Sean Follmer. 2018. Investigating tangible collaboration for design towards augmented physical telepresence. In *Design thinking research*. Springer, 131–145. https://doi.org/10.1007/978-3-319-60967-6_7
- [402] J Ernesto Solanes, Adolfo Muñoz, Luis Gracia, Ana Martí, Vicent Girbés-Juan, and Josep Tornero. 2020. Teleoperation of industrial robot manipulators based on augmented reality. *The International Journal of Advanced Manufacturing Technology* 111, 3 (2020), 1077–1097. <https://doi.org/10.1007/s00170-020-05997-1>
- [403] Sichao Song and Seiji Yamada. 2018. Bioluminescence-inspired human-robot interaction: designing expressive lights that affect human's willingness to interact with a robot. In *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 224–232. <https://doi.org/10.1145/3171221.3171249>
- [404] Adam Sosa, Richard Stanton, Stepheny Perez, Christian Keyes-Garcia, Sara Gonzalez, and Zachary O Tóups. 2015. Imperfect robot control in a mixed reality game to teach hybrid human-robot team coordination. In *Proceedings of the 2015 Annual Symposium on Computer-Human Interaction in Play*. 697–702. <https://doi.org/10.1145/2793107.2810288>
- [405] Maximilian Speicher, Brian D Hall, and Michael Nebeling. 2019. What is mixed reality?. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 1–15. <https://doi.org/10.1145/3290605.3300767>
- [406] Aaron St. Clair and Maja Mataric. 2015. How robot verbal feedback can improve team performance in human-robot task collaborations. In *Proceedings of the tenth annual acm/ieee international conference on human-robot interaction*. 213–220. <https://doi.org/10.1145/2696454.2696491>
- [407] Susanne Stadler, Kevin Kain, Manuel Giuliani, Nicole Mirlig, Gerald Stollnberger, and Manfred Tscheligi. 2016. Augmented reality for industrial robot programmers: Workload analysis for task-based, augmented reality-supported robot control. In *2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 179–184. <https://doi.org/10.1109/ROMAN.2016.7745108>
- [408] Gordon Stein and Ákos Lédeczi. 2019. Mixed reality robotics for stem education. In *2019 IEEE Blocks and Beyond Workshop (B&B)*. IEEE, 49–53. <https://doi.org/10.1109/bb48857.2019.8941229>
- [409] Camille Linick Stewart, Abigail Fong, Govinda Payyavula, Simon DiMaio, Kelly Lafaro, Kirsten Tallmon, Sherry Wren, Jonathan Sörger, and Yuman Fong. 2021. Study on augmented reality for robotic surgery bedside assistants. *Journal of Robotic Surgery* (2021), 1–8. <https://doi.org/10.1007/s11701-021-01335-z>

- [410] Dominykas Strazdas, Jan Hintz, and Ayoub Al-Hamadi. 2021. Robo-HUD: Interaction Concept for Contactless Operation of Industrial Cobotic Systems. *Applied Sciences* 11, 12 (2021), 5366. <https://doi.org/10.3390/APP11125366>
- [411] Li-Ming Su, Balazs P Vagvolgyi, Rahul Agarwal, Carol E Reiley, Russell H Taylor, and Gregory D Hager. 2009. Augmented reality during robot-assisted laparoscopic partial nephrectomy: toward real-time 3D-CT to stereoscopic video registration. *Urology* 73, 4 (2009), 896–900. <https://doi.org/10.1016/j.jurology.2008.11.040>
- [412] Mu-Chun Su, Gwo-Dong Chen, Yi-Shan Tsai, Ren-Hao Yao, Chung-Kuang Chou, Yohannes Budiono Jinawi, De-Yuan Huang, Yi-Zeng Hsieh, and Shih-Chieh Lin. 2009. Design of an Interactive Table for Mixed-Reality Learning Environments. In *International Conference on Technologies for E-Learning and Digital Entertainment*. Springer, 489–494. https://doi.org/10.1007/978-3-642-03364-3_59
- [413] Yun-Peng Su, Xiao-Qi Chen, Tony Zhou, Christopher Pretty, and J Geoffrey Chase. 2021. Mixed Reality-Enhanced Intuitive Teleoperation with Hybrid Virtual Fixtures for Intelligent Robotic Welding. *Applied Sciences* 11, 23 (2021), 11280. <https://doi.org/10.3390/app112311280>
- [414] EK Subin, Ashik Hameed, and AP Sudheer. 2017. Android based augmented reality as a social interface for low cost social robots. In *Proceedings of the Advances in Robotics*. 1–4. <https://doi.org/10.1145/3132446.3134907>
- [415] Masanori Sugimoto. 2011. A mobile mixed-reality environment for children's storytelling using a handheld projector and a robot. *IEEE Transactions on Learning Technologies* 4, 3 (2011), 249–260. <https://doi.org/10.1109/tlt.2011.13>
- [416] Masanori Sugimoto, Tomoki Fujita, Haipeng Mi, and Aleksander Krzywinski. 2011. RoboTable2: a novel programming environment using physical robots on a tabletop platform. In *Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology*. 1–8. <https://doi.org/10.1145/2071423.2071436>
- [417] Maki Sugimoto, Georges Kagotani, Hideaki Nii, Naoji Shiroma, Fumitoshi Matsuno, and Masahiko Inami. 2005. Time Follower's Vision: a teleoperation interface with past images. *IEEE Computer Graphics and Applications* 25, 1 (2005), 54–63. <https://doi.org/10.1109/mcg.2005.23>
- [418] Ippei Suzuki, Shuntarou Yoshimitsu, Keisuke Kawahara, Nobutaka Ito, Atsushi Shinoda, Akira Ishii, Takatoshi Yoshida, and Yoichi Ochiai. 2016. Gushed diffusers: Fast-moving, floating, and lightweight midair display. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology*. 69–70. <https://doi.org/10.1145/2984751.2985706>
- [419] Naoki Suzuki and Asaki Hattori. 2012. Development of new augmented reality function using intraperitoneal multi-view camera. In *Workshop on Augmented Environments for Computer-Assisted Interventions*. Springer, 67–76. https://doi.org/10.1007/978-3-642-38085-3_8
- [420] Naoki Suzuki, Asaki Hattori, Kazuo Tanoue, Satoshi Ieiri, Kozo Konishi, Morimasa Tomikawa, Hajime Kenmotsu, and Makoto Hashizume. 2010. Scorpion shaped endoscopic surgical robot for NOTES and SPS with augmented reality functions. In *International Workshop on Medical Imaging and Virtual Reality*. Springer, 541–550. https://doi.org/10.1007/978-3-642-15699-1_57
- [421] Ryo Suzuki, Hooman Hedayati, Clement Zheng, James L Bohn, Daniel Szafrir, Ellen Yi-Luen Do, Mark D Gross, and Daniel Leithinger. 2020. Roomshift: Room-scale dynamic haptics for vr with furniture-moving swarm robots. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–11. <https://doi.org/10.1145/3313831.3376523>
- [422] Ryo Suzuki, Jun Kato, Mark D Gross, and Tom Yeh. 2018. Reactile: Programming swarm user interfaces through direct physical manipulation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–13. <https://doi.org/10.1145/3173574.3173773>
- [423] Ryo Suzuki, Rubaiat Habib Kazi, Li-Yi Wei, Stephen DiVerdi, Wilmot Li, and Daniel Leithinger. 2020. RealitySketch: Embedding Responsive Graphics and Visualizations in AR through Dynamic Sketching. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*. 166–181. <https://doi.org/10.1145/3379337.3415892>
- [424] Ryo Suzuki, Eyal Ofek, Mike Sinclair, Daniel Leithinger, and Mar Gonzalez-Franco. 2021. HapticBots: Distributed Encountered-type Haptics for VR with Multiple Shape-changing Mobile Robots. In *The 34th Annual ACM Symposium on User Interface Software and Technology*. 1269–1281. <https://doi.org/10.1145/3472749.3474821>
- [425] Ryo Suzuki, Clement Zheng, Yasuaki Kakehi, Tom Yeh, Ellen Yi-Luen Do, Mark D Gross, and Daniel Leithinger. 2019. Shapebots: Shape-changing swarm robots. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology*. 493–505. <https://doi.org/10.1145/3332165.3347911>
- [426] Daniel Szafrir, Bilge Mutlu, and Terrence Fong. 2014. Communication of intent in assistive free flyers. In *2014 9th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 358–365. <https://doi.org/10.1145/2559636.2559672>
- [427] Daniel Szafrir, Bilge Mutlu, and Terrence Fong. 2015. Communicating directionality in flying robots. In *2015 10th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 19–26. <https://doi.org/10.1145/2696454.2696475>
- [428] Daniel Szafrir and Danielle Albers Szafrir. 2021. Connecting Human-Robot Interaction and Data Visualization. In *Proceedings of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*. 281–292. <https://doi.org/10.1145/3434073.3444683>
- [429] Faisal Taher, John Hardy, Abhijit Karnik, Christian Weichel, Yvonne Jansen, Kasper Hornbaek, and Jason Alexander. 2015. Exploring interactions with physically dynamic bar charts. In *Proceedings of the 33rd annual acm conference on human factors in computing systems*. 3237–3246. <https://doi.org/10.1145/2702123.2702604>
- [430] Kazuki Takashima, Naohiro Aida, Hitomi Yokoyama, and Yoshifumi Kitamura. 2013. TransformTable: a self-actuated shape-changing digital table. In *Proceedings of the 2013 ACM international conference on Interactive tablespots and surfaces*. 179–188. <https://doi.org/10.1145/2512349.2512818>
- [431] Kazuki Takashima, Takaumi Oyama, Yusuke Asari, Ehud Sharlin, Saul Greenberg, and Yoshifumi Kitamura. 2016. Study and design of a shape-shifting wall display. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*. 796–806. <https://doi.org/10.1145/2901790.2901892>
- [432] Leonardo Tanzi, Pietro Piazzolla, Francesco Porziglia, and Enrico Vezzetti. 2021. Real-time deep learning semantic segmentation during intra-operative surgery for 3D augmented reality assistance. *International Journal of Computer Assisted Radiology and Surgery* 16, 9 (2021), 1435–1445. <https://doi.org/10.1007/s11548-021-02423-y>
- [433] Pedro Tavares, Carlos M Costa, Luís Rocha, Pedro Malaca, Pedro Costa, António P Moreira, Armando Sousa, and Germano Veiga. 2019. Collaborative welding system using BIM for robotic reprogramming and spatial augmented reality. *Automation in Construction* 106 (2019), 102825. <https://doi.org/10.1016/J.AUTCON.2019.04.020>
- [434] Frank Thomas, Ollie Johnston, and Frank Thomas. 1995. *The illusion of life: Disney animation*. Hyperion New York.
- [435] Rundong Tian and Eric Paulos. 2021. Adroid: Augmenting Hands-on Making with a Collaborative Robot. In *Proceedings of the 34th Annual ACM Symposium on User Interface Software and Technology*. <https://doi.org/10.1145/3472749.3474749>
- [436] Hiroaki Tobita, Shigeaki Maruyama, and Takuya Kuji. 2011. Floating avatar: blimp-based telepresence system for communication and entertainment. In *ACM SIGGRAPH 2011 Emerging Technologies*. 1–1. <https://doi.org/10.1145/2048259.2048263>
- [437] Junya Tominaga, Kensaku Kawauchi, and Jun Rekimoto. 2014. Around me: a system with an escort robot providing a sports player's self-images. In *Proceedings of the 5th Augmented Human International Conference*. 1–8. <https://doi.org/10.1145/2582051.2582094>
- [438] Bethan Hannah Topliss, Sanna M Pampel, Gary Burnett, Lee Skrypchuk, and Chrisminder Hare. 2018. Establishing the role of a virtual lead vehicle as a novel augmented reality navigational aid. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 137–145. <https://doi.org/10.1145/3239060.3239069>
- [439] Nhan Tran. 2020. *Exploring mixed reality robot communication under different types of mental workload*. Colorado School of Mines. <https://doi.org/10.31219/osf.io/f3a8c>
- [440] Nhan Tran, Trevor Grant, Thao Phung, Leanne Hirshfield, Christopher Wickens, and Tom Williams. 2021. Get This! Mixed Reality Improves Robot Communication Regardless of Mental Workload. In *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*. 412–416. <https://doi.org/10.1145/3434074.3447203>
- [441] Nhan Tran, Trevor Grant, Thao Phung, Leanne Hirshfield, Christopher Wickens, and Tom Williams. 2021. Robot-Generated Mixed Reality Gestures Improve Human-Robot Interaction. In *International Conference on Social Robotics*. Springer, 768–773. https://doi.org/10.1007/978-3-030-90525-5_69
- [442] Jörg Traub, Marco Feuerstein, Martin Bauer, Eva U Schirmbeck, Hesam Najafi, Robert Bauernschmitt, and Gudrun Klinker. 2004. Augmented reality for port placement and navigation in robotically assisted minimally invasive cardiovascular surgery. In *International Congress Series*, Vol. 1268. Elsevier, 735–740. <https://doi.org/10.1016/J.IJCS.2004.03.049>
- [443] Jaryd Urbani, Mohammed Al-Sada, Tatsuo Nakajima, and Thomas Höglund. 2018. Exploring Augmented Reality Interaction for Everyday Multipurpose Wearable Robots. In *2018 IEEE 24th International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA)*. IEEE, 209–216. <https://doi.org/10.1109/RTCSA.2018.00033>
- [444] AJN Van Bremen. 2004. Bringing robots to life: Applying principles of animation to robots. In *Proceedings of Shaping Human-Robot Interaction workshop held at CHI*, Vol. 2004. Citeseer, 143–144.
- [445] Ana M Villanueva, Ziyi Liu, Zhengzhe Zhu, Xin Du, Joey Huang, Kylie A Pepler, and Karthik Ramani. 2021. RobotAR: An Augmented Reality Compatible Teleconsulting Robotics Toolkit for Augmented Makerspace Experiences. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–13. <https://doi.org/10.1145/3411764.3445726>
- [446] Daniel Vogel and Ravin Balakrishnan. 2004. Interactive public ambient displays: transitioning from implicit to explicit, public to personal, interaction with multiple users. In *Proceedings of the 17th annual ACM symposium on User interface software and technology*. 137–146. <https://doi.org/10.1145/1029632.1029656>

- [447] Francesco Volonté, François Pugin, Pascal Bucher, Maki Sugimoto, Osman Ratib, and Philippe Morel. 2011. Augmented reality and image overlay navigation with OsiriX in laparoscopic and robotic surgery: not only a matter of fashion. *Journal of Hepato-biliary-pancreatic Sciences* 18, 4 (2011), 506–509. <https://doi.org/10.1007/s00534-011-0385-6>
- [448] Sebastian von Mammen, Heiko Hamann, and Michael Heider. 2016. Robot gardens: an augmented reality prototype for plant-robot biohybrid systems. In *Proceedings of the 22nd ACM Conference on Virtual Reality Software and Technology*. 139–142. <https://doi.org/10.1145/2993369.2993400>
- [449] Emanuel Vonach, Clemens Gatterer, and Hannes Kaufmann. 2017. VRRobot: Robot actuated props in an infinite virtual environment. In *2017 IEEE Virtual Reality (VR)*. IEEE, 74–83. <https://doi.org/10.1109/VR.2017.7892233>
- [450] Michael Walker, Hooman Hedayati, Jennifer Lee, and Daniel Szafir. 2018. Communicating robot motion intent with augmented reality. In *Proceedings of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*. 316–324. <https://doi.org/10.1145/3171221.3171253>
- [451] Michael E. Walker, Hooman Hedayati, and Daniel Szafir. 2019. Robot teleoperation with augmented reality virtual surrogates. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 202–210. <https://doi.org/10.1109/HRI.2019.8673306>
- [452] DA Wang, Fernando Bello, and Ara Darzi. 2004. Augmented reality provision in robotically assisted minimally invasive surgery. In *International Congress Series*, Vol. 1268. Elsevier, 527–532. <https://doi.org/10.1016/j.ijcs.2004.03.057>
- [453] Guoping Wang, Xuechen Chen, Sheng Liu, Chingping Wong, and Sheng Chu. 2016. Mechanical chameleon through dynamic real-time plasmonic tuning. *Academy of Science Nano* 10, 2 (2016), 1788–1794. <https://doi.org/10.1021/acsnano.5b07472>
- [454] Qiang Wang, Xiumin Fan, Mingyu Luo, Xuyue Yin, and Wenmin Zhu. 2020. Construction of Human-Robot Cooperation Assembly Simulation System Based on Augmented Reality. In *International Conference on Human-Computer Interaction*. Springer, 629–642. https://doi.org/10.1007/978-3-030-49695-1_42
- [455] Tianyi Wang, Xun Qian, Fengming He, Xiyun Hu, Ke Huo, Yuanzhi Cao, and Karthik Ramani. 2020. CAPturAR: An Augmented Reality Tool for Authoring Human-Involved Context-Aware Applications. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*. 328–341. <https://doi.org/10.1145/3379337.3415815>
- [456] Xi Vincent Wang, Lihui Wang, Mingtian Lei, and Yongqing Zhao. 2020. Closed-loop augmented reality towards accurate human-robot collaboration. *CIRP annals* 69, 1 (2020), 425–428. <https://doi.org/10.1016/j.cirp.2020.03.014>
- [457] Jonas Wassermann, Axel Vick, and Jörg Krüger. 2018. Intuitive robot programming through environment perception, augmented reality simulation and automated program verification. *Procedia CIRP* 76 (2018), 161–166. <https://doi.org/10.1016/j.procir.2018.01.036>
- [458] Atsushi Watanabe, Tetsushi Ikeda, Yoichi Morales, Kazuhiko Shinozawa, Takahiro Miyashita, and Norihiro Hagita. 2015. Communicating robotic navigational intentions. In *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 5763–5769. <https://doi.org/10.1109/IROS.2015.7354195>
- [459] Rong Wen, Chin-Boon Chng, and Chee-Kong Chui. 2017. Augmented reality guidance with multimodality imaging data and depth-perceived interaction for robot-assisted surgery. *Robotics* 6, 2 (2017), 13. <https://doi.org/10.3390/robotics6020013>
- [460] Rong Wen, Chin-Boon Chng, Chee-Kong Chui, Kah-Bin Lim, Sim-Heng Ong, and Stephen Kin-Yong Chang. 2012. Robot-assisted RF ablation with interactive planning and mixed reality guidance. In *2012 IEEE/SICE International Symposium on System Integration (SII)*. IEEE, 31–36. <https://doi.org/10.1109/SII.2012.6426963>
- [461] Rong Wen, Wei-Liang Tay, Binh P Nguyen, Chin-Boon Chng, and Chee-Kong Chui. 2014. Hand gesture guided robot-assisted surgery based on a direct augmented reality interface. *Computer methods and programs in biomedicine* 116, 2 (2014), 68–80. <https://doi.org/10.1016/j.cmpb.2013.12.018>
- [462] Wesley Willett, Bon Adriel Aseniero, Sheelagh Carpendale, Pierre Dragicevic, Yvonne Jansen, Lora Oehlberg, and Petra Isenberg. 2021. Perception! Immersion! Empowerment!: Superpowers as Inspiration for Visualization. *IEEE Transactions on Visualization and Computer Graphics* (2021). <https://doi.org/10.1109/TVCG.2021.3114844>
- [463] Wesley Willett, Yvonne Jansen, and Pierre Dragicevic. 2016. Embedded data representations. *IEEE transactions on visualization and computer graphics* 23, 1 (2016), 461–470. <https://doi.org/10.1109/TVCG.2016.2598608>
- [464] Tom Williams, Matthew Bussing, Sebastian Cabrol, Elizabeth Boyle, and Nhan Tran. 2019. Mixed reality deictic gesture for multi-modal robot communication. In *2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 191–201. <https://doi.org/10.1109/hri.2019.8673275>
- [465] Tom Williams, Leanne Hirshfield, Nhan Tran, Trevor Grant, and Nicholas Woodward. 2020. Using augmented reality to better study human-robot interaction. In *International Conference on Human-Computer Interaction*. Springer, 643–654. https://doi.org/10.1007/978-3-030-49695-1_43
- [466] Tom Williams, Daniel Szafir, Tathagata Chakraborti, and Heni Ben Amor. 2018. Virtual, augmented, and mixed reality for human-robot interaction. In *Companion of the 2018 ACM/IEEE International Conference on Human-Robot Interaction*.
- [467] Ryan Wistort and Cynthia Breazeal. 2011. TofuDraw: A mixed-reality choreography tool for authoring robot character performance. In *Proceedings of the 10th International Conference on Interaction Design and Children*. 213–216. <https://doi.org/10.1145/1999030.1999064>
- [468] Mulun Wu, Shi-Lu Dai, and Chenguang Yang. 2020. Mixed reality enhanced user interactive path planning for omnidirectional mobile robot. *Applied Sciences* 10, 3 (2020), 1135. <https://doi.org/10.3390/app10031135>
- [469] Mulun Wu, Yanbin Xu, Chenguang Yang, and Ying Feng. 2018. Omnidirectional mobile robot control based on mixed reality and semg signals. In *2018 Chinese Automation Congress (CAC)*. IEEE, 1867–1872. <https://doi.org/10.1109/cac.2018.8623114>
- [470] Tian Xia, Simon Léonard, Anton Deguet, Louis Whitcomb, and Peter Kazanzides. 2012. Augmented reality environment with virtual fixtures for robotic telemanipulation in space. In *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*. IEEE, 5059–5064. <https://doi.org/10.1109/iros.2012.6386169>
- [471] Siyuan Xiang, Ruoyu Wang, and Chen Feng. 2021. Mobile projective augmented reality for collaborative robots in construction. *Automation in Construction* 127 (2021), 103704. <https://doi.org/10.1016/J.AUTCON.2021.103704>
- [472] Xiao Xiao, Paula Aguilera, Jonathan Williams, and Hiroshi Ishii. 2013. MirrorFugue iii: conjuring the recorded pianist.. In *CHI Extended Abstracts*. Citeseer, 2891–2892. <https://doi.org/10.1145/2468356.2479564>
- [473] Xiao Xiao, Pablo Puentes, Edith Ackermann, and Hiroshi Ishii. 2016. Andantino: Teaching children piano with projected animated characters. In *Proceedings of the the 15th international conference on interaction design and children*. 37–45. <https://doi.org/10.1145/2930674.2930689>
- [474] Chung Xue, Yiansong Qiao, and Niall Murray. 2020. Enabling Human-Robot-Interaction for remote robotic operation via Augmented Reality. In *2020 IEEE 21st International Symposium on "A World of Wireless, Mobile and Multimedia Networks"(WoWMoM)*. IEEE, 194–196. <https://doi.org/10.1109/wowmom49955.2020.000046>
- [475] Wataru Yamada, Kazuhiro Yamada, Hiroyuki Manabe, and Daizo Ikeda. 2017. iSphere: self-luminous spherical drone display. In *Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology*. 635–643. <https://doi.org/10.1145/3126594.3126631>
- [476] Junichi Yamaoka and Yasuaki Kakehi. 2016. MiragePrinter: interactive fabrication on a 3D printer with a mid-air display. In *ACM SIGGRAPH 2016 Studio*. 1–2. <https://doi.org/10.1145/2929484.2929489>
- [477] AWW Yew, SK Ong, and AYC Nee. 2017. Immersive augmented reality environment for the teleoperation of maintenance robots. *Procedia CIRP* 61 (2017), 305–310. <https://doi.org/10.1016/J.PROCIR.2016.11.183>
- [478] Yan Xixian, Kazuki Takashima, Anthony Tang, Takayuki Tanno, Kazuyuki Fujita, and Yoshifumi Kitamura. 2020. Zoomwalls: Dynamic walls that simulate haptic infrastructure for room-scale vr world. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*. 223–235. <https://doi.org/10.1145/3379337.3415859>
- [479] James Young and Ehud Sharlin. 2006. A Mixed Reality Approach to Human-Robot Interaction. (2006). <https://doi.org/10.11575/PRISM/30998>
- [480] James Young, Ehud Sharlin, and Takeo Igarashi. 2011. What is mixed reality, anyway? Considering the boundaries of mixed reality in the context of robots. In *Mixed Reality and Human-Robot Interaction*. Springer, 1–11. https://doi.org/10.1007/978-94-007-0582-1_1
- [481] James E Young, Min Xin, and Ehud Sharlin. 2007. Robot expressionism through cartooning. In *2007 2nd ACM/IEEE International Conference on Human-Robot Interaction (HRI)*. IEEE, 309–316. <https://doi.org/10.1145/1228716.1228758>
- [482] Liangzhe Yuan, Christopher Reardon, Garrett Warnell, and Giuseppe Loianno. 2019. Human gaze-driven spatial tasking of an autonomous MAV. *IEEE Robotics and Automation Letters* 4, 2 (2019), 1343–1350. <https://doi.org/10.1109/LRA.2019.2895419>
- [483] Ludek Zalud. 2007. Augmented reality user interface for reconnaissance robotic missions. In *RO-MAN 2007-The 16th IEEE International Symposium on Robot and Human Interactive Communication*. IEEE, 974–979. <https://doi.org/10.1109/roman.2007.4415224>
- [484] Ludek Zalud, Petra Kocmanova, Frantisek Burian, and Tomas Jilek. 2014. Color and thermal image fusion for augmented reality in rescue robotics. In *The 8th International Conference on Robotic, Vision, Signal Processing & Power Applications*. Springer, 47–55. https://doi.org/10.1007/978-981-4585-42-2_6
- [485] Bowei Zeng, Fanle Meng, Hui Ding, and Guangzhi Wang. 2017. A surgical robot with augmented reality visualization for stereoelectroencephalography electrode implantation. *International journal of computer assisted radiology and surgery* 12, 8 (2017), 1355–1368. <https://doi.org/10.1007/s11548-017-1634-1>
- [486] Dongpu Zhang, Lin Tian, Kewu Huang, and Jiwu Wang. 2020. Vision Tracking Algorithm for Augmented Reality System of Teleoperation Mobile Robots. In *2020 3rd International Conference on Unmanned Systems (ICUS)*. IEEE, 1047–1052. <https://doi.org/10.1109/icus50048.2020.9274917>
- [487] Fengxin Zhang, Chow Yin Lai, Milan Simic, and Songlin Ding. 2020. Augmented reality in robot programming. *Procedia Computer Science* 176 (2020), 1221–1230. <https://doi.org/10.1016/j.procs.2020.09.119>

- [488] Renjie Zhang, Xinyu Liu, Jiazhou Shuai, and Lianyu Zheng. 2020. Collaborative robot and mixed reality assisted microgravity assembly for large space mechanism. *Procedia Manufacturing* 51 (2020), 38–45. <https://doi.org/10.1016/j.promfg.2020.10.007>
- [489] Zhou Zhao, Panfeng Huang, Zhenyu Lu, and Zhengxiong Liu. 2017. Augmented reality for enhancing tele-robotic system with force feedback. *Robotics and Autonomous Systems* 96 (2017), 93–101. <https://doi.org/10.1016/j.robot.2017.05.017>
- [490] Allan Zhou, Dylan Hadfield-Menell, Anusha Nagabandi, and Anca D Dragan. 2017. Expressive robot motion timing. In *Proceedings of the 2017 ACM/IEEE International Conference on Human-Robot Interaction*. ACM, 22–31. <https://doi.org/10.1145/2909824.3020221>
- [491] Chaozheng Zhou, Ming Zhu, Yunyong Shi, Li Lin, Gang Chai, Yan Zhang, and Le Xie. 2017. Robot-assisted surgery for mandibular angle split osteotomy using augmented reality: preliminary results on clinical animal experiment. *Aesthetic plastic surgery* 41, 5 (2017), 1228–1236. <https://doi.org/10.1007/s00266-017-0900-5>
- [492] Danny Zhu and Manuela Veloso. 2016. Virtually adapted reality and algorithm visualization for autonomous robots. In *Robot World Cup*. Springer, 452–464.
- https://doi.org/10.1007/978-3-319-68792-6_38
- [493] Kamil Židek, Ján Pitel', Michal Balog, Alexander Hošovský, Vratislav Hladký, Peter Lazorík, Angelina Ľakovčík, and Jakub Demčák. 2021. CNN Training Using 3D Virtual Models for Assisted Assembly with Mixed Reality and Collaborative Robots. *Applied Sciences* 11, 9 (2021), 4269. <https://doi.org/10.3390/APP11094269>
- [494] Stefanie Zollmann, Christof Hoppe, Tobias Langlotz, and Gerhard Reitmayr. 2014. Flyar: Augmented reality supported micro aerial vehicle navigation. *IEEE transactions on visualization and computer graphics* 20, 4 (2014), 560–568. <https://doi.org/10.1109/TVCG.2014.24>
- [495] Mark Zolotas, Joshua Elsdon, and Yiannis Demiris. 2018. Head-mounted augmented reality for explainable robotic wheelchair assistance. In *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. IEEE, 1823–1829. <https://doi.org/10.1109/iros.2018.8594002>
- [496] Wenchao Zou, Mayur Andulkar, and Ulrich Berger. 2018. Development of Robot Programming System through the use of Augmented Reality for Assembly Tasks. In *ISR 2018; 50th International Symposium on Robotics*. VDE, 1–7. <https://doi.org/10.1201/9781439863992-10>

Appendix Table: Full Citation List

| Category | Count | Citations |
|--|-------|---|
| Section 3. Approaches to Augmenting Reality in Robotics | | |
| Augment Robots | | |
| → On-Body (Head and Eye) | 103 | Figure: [198] — [25–27, 30, 31, 33, 42, 43, 46–48, 51, 52, 59, 61, 67, 69, 76, 78, 80, 83, 85, 103, 107–109, 114, 118, 126, 134, 137, 156, 158, 160–162, 165, 174, 180, 181, 188, 189, 194, 197, 198, 200, 209, 211, 220, 224–226, 231, 252, 262, 267, 271, 283, 285, 287, 290, 292, 296, 297, 301, 302, 315, 323–327, 329, 342, 352, 354, 358, 360, 363, 366, 367, 372, 375, 376, 379, 387, 393, 396–398, 400, 413, 443, 450, 451, 454, 456, 474, 477, 481, 482, 487, 488] |
| → On-Body (Handheld) | 26 | Figure: [481] — [9, 18, 19, 53, 55, 76, 101, 115, 130, 131, 133, 136, 144, 153, 195, 206, 209, 243, 263, 275, 305, 328, 373, 414, 481, 494] |
| → On-Environment | 74 | Figure: [431] — [9, 13, 15, 21, 31, 44, 45, 48, 64, 71, 73, 74, 82, 84, 92, 96, 101, 102, 104, 110, 115, 116, 120–124, 127, 128, 143, 145, 146, 159, 163, 167, 169, 193, 212, 216, 221, 243–245, 253, 258, 265, 284, 286, 290, 306, 310, 312, 313, 328, 330, 333–335, 365, 369, 374, 378, 380, 388, 395, 410, 417, 429–431, 442, 472, 489, 492] |
| → On-Robot | 9 | Figure: [14] — [14, 210, 382, 391, 418, 436, 445, 475] |
| Augment Surroundings | | |
| → On-Body (Head and Eye) | 146 | Figure: [341] — [11, 24–27, 29, 30, 33, 38, 39, 43, 47, 51, 54, 56, 59, 61, 66, 67, 69, 76, 79, 80, 85, 86, 93, 98, 105, 111, 114, 118, 119, 125, 126, 137, 139, 141, 149, 156, 158, 161, 165, 171, 174, 177, 181, 182, 184, 185, 189, 190, 194, 196, 199, 200, 205, 211, 213, 215, 220, 222, 224–226, 231, 234, 237, 238, 241, 242, 248, 252, 255, 256, 262, 267, 270, 274, 278, 282, 283, 285, 287, 292, 296, 297, 301, 302, 315, 323, 325–327, 329, 332, 333, 336, 341–343, 352, 354, 355, 357, 358, 360–363, 366, 367, 372, 376, 379, 381, 394, 396–398, 400, 402, 409, 413, 439–441, 443, 448, 450, 451, 454, 456, 457, 464, 468–470, 477, 479, 480, 482, 483, 488, 491, 493, 495] |
| → On-Body (Handheld) | 28 | Figure: [140] — [19, 53, 55, 62, 63, 76, 89, 101, 131–133, 135, 136, 144, 149, 153, 177, 201, 206, 228, 232, 263, 275, 295, 305, 407, 481, 494] |
| → On-Environment | 139 | Figure: [140] — [13, 15, 20, 21, 33, 35, 44, 45, 49, 50, 71–74, 77, 82, 88, 90–92, 94, 96, 102, 110, 116, 117, 120–124, 128, 138, 140, 142, 143, 145–147, 149, 150, 157, 163, 164, 167, 169, 177, 178, 183, 187, 188, 191, 207, 212, 216, 221, 223, 229, 230, 233, 239, 240, 246, 251, 253, 257, 264, 265, 268, 269, 272, 273, 279, 282, 284, 288, 289, 303, 306, 309, 310, 312, 313, 318, 319, 333–335, 340, 343, 344, 346–348, 350, 351, 369–371, 377, 380, 383–385, 388, 389, 404, 406, 408, 410–412, 415, 416, 419, 420, 425, 433, 436, 438, 442, 447, 451, 452, 459–461, 465, 467, 468, 471, 473, 484–486, 489, 492, 496] |
| → On-Robot | 33 | Figure: [112] — [10, 12, 58, 65, 91, 112, 166, 168, 188, 203, 204, 210, 249, 250, 261, 266, 300, 314, 317, 319, 320, 337, 338, 368, 370, 382, 418, 432, 435, 437, 445, 458, 476] |

| Category | Count | Citations |
|---|-------|--|
| Section 4. Characteristics of Augmented Robots | | |
| Form Factors | | |
| → Robotic Arms | 172 | Figure: [79] — [9, 12, 13, 20, 21, 24–27, 30, 33, 35, 39, 42, 44, 45, 47, 48, 51–53, 56, 59, 61, 63, 66, 67, 69, 72, 74, 77, 79, 80, 82–85, 92, 94, 98, 101, 103–105, 110, 118–126, 128, 132, 133, 136, 138, 140, 143, 147, 150, 153, 160–162, 164, 169, 174, 181, 182, 185, 187, 190, 194–196, 203, 204, 207, 215, 216, 222, 225, 226, 231, 232, 248, 250–253, 255–257, 262, 264, 270, 274, 279, 282, 283, 285, 286, 288–290, 292, 297, 301, 309, 310, 312, 313, 319, 323–327, 329, 330, 336, 341, 347, 348, 352, 354, 355, 358, 372, 378, 379, 383–385, 389, 394, 396–398, 400, 402, 409–411, 413, 420, 432, 433, 435, 442, 447, 448, 452, 454, 456, 457, 459–461, 470, 474, 477, 485, 487–489, 491, 493, 496] |
| → Drones | 25 | Figure: [96] — [15, 38, 58, 76, 78, 96, 114, 157, 171, 177, 184, 209, 227, 261, 317, 332, 382, 388, 436, 450, 451, 475, 482, 492, 494] |
| → Mobile Robots | 133 | Figure: [468] — [10, 18, 19, 29, 43, 49, 50, 52–55, 62, 64, 66, 71, 73, 88–91, 101, 102, 107–109, 112, 115, 117, 131, 135, 136, 142, 144–146, 156, 163, 165, 169, 174, 177, 178, 180, 188, 189, 191, 197, 199–201, 205, 209–212, 221, 224, 225, 228–230, 233, 234, 237, 238, 241, 249, 263, 265–269, 272, 273, 275, 284, 296, 305, 306, 318, 327, 328, 333, 335, 340, 343, 344, 346, 350, 351, 357, 360–363, 365, 368–371, 373, 375, 377, 380, 381, 391, 393, 404, 406–408, 412, 414–418, 425, 437, 445, 451, 464, 467–469, 471, 479–481, 483, 484, 486] |
| → Humanoid Robots | 33 | Figure: [440] — [11, 14, 29, 46, 59, 93, 111, 134, 137, 139, 141, 149, 158, 166, 183, 213, 220, 254, 262, 271, 278, 295, 315, 342, 366, 367, 372, 376, 395, 439–441, 465] |
| → Vehicles | 9 | Figure: [320] — [2, 7, 223, 300, 314, 320, 438, 458, 495] |
| → Actuated Objects | 28 | Figure: [245] — [116, 117, 127, 130, 136, 159, 167, 168, 193, 209, 240, 242–246, 258, 287, 303, 334, 374, 387, 429–431, 443, 472, 473] |
| → Combinations | 14 | Figure: [98] — [29, 52, 53, 66, 98, 101, 117, 136, 169, 174, 177, 209, 225, 327] |
| → Other Types | 12 | Figure: [304] — [31, 65, 86, 136, 206, 239, 302, 304, 337, 338, 443, 476] |
| Relationship | | |
| → 1 : 1 | 324 | Figure: [153] — [9, 11, 12, 14, 15, 18–21, 24–27, 29, 30, 33, 35, 38, 39, 42–47, 49–56, 58, 59, 61–67, 69, 72–74, 76, 79, 80, 82–86, 88, 89, 92–94, 96, 98, 102–105, 108–111, 114–128, 130, 132–141, 143, 144, 147, 149, 150, 153, 156–158, 160–162, 164, 165, 167, 169, 171, 174, 177, 180–185, 187–191, 193–197, 199, 201, 203–207, 209–211, 213, 215, 216, 220, 222–234, 237–239, 241–245, 249–253, 255–258, 262, 264, 266–274, 278, 279, 282, 283, 285–290, 292, 295–297, 300, 302, 303, 305, 309, 310, 312–315, 318, 319, 323–326, 329, 330, 332–337, 341, 342, 346–348, 350–352, 354, 355, 357, 358, 360–363, 365–368, 370–374, 376–381, 383–385, 389, 393, 394, 396–398, 400, 402, 406, 407, 409, 411, 413, 414, 417, 419, 420, 429, 432, 433, 435, 437–443, 445, 447, 450, 452, 454, 456–460, 464, 465, 467–474, 476, 477, 479–489, 491–496] |
| → 1 : m | 34 | Figure: [131] — [13, 48, 78, 90, 101, 107, 131, 142, 145, 163, 176–178, 212, 235, 240, 246, 248, 263, 265, 284, 301, 306, 327, 328, 340, 344, 387, 388, 391, 395, 416, 425, 448] |
| → n : 1 | 25 | Figure: [430] — [10, 31, 77, 91, 112, 146, 159, 166, 168, 275, 317, 320, 338, 343, 345, 364, 369, 382, 404, 410, 418, 430, 436, 461, 475] |
| → n : m | 10 | Figure: [328] — [71, 200, 221, 328, 375, 408, 412, 415, 431, 451] |
| Scale | | |
| → Handheld-scale | 19 | Figure: [179] — [39, 46, 71, 86, 179, 237, 238, 258, 273, 296, 303, 306, 328, 351, 374, 412, 419, 425, 443] |
| → Tabletop-scale | 70 | Figure: [257] — [11, 14, 18, 19, 49, 50, 52, 55, 61, 72, 78, 83, 90, 116, 117, 127, 130, 136, 142, 146, 156, 157, 159, 163, 167, 178, 187, 193, 196, 201, 206, 212, 213, 221, 234, 239, 242–246, 257, 268, 275, 278, 284, 297, 327, 330, 333, 335, 340, 343, 348, 360, 362, 365, 371, 380, 407, 408, 416, 429, 445, 451, 476, 480, 484, 487, 489] |
| → Body-scale | 255 | Figure: [289] — [9, 10, 12, 13, 20, 21, 24–27, 29–31, 33, 35, 38, 42, 44, 45, 47, 48, 51, 53, 56, 59, 63, 65, 67, 69, 73, 74, 76, 77, 79, 80, 82, 85, 88, 91–94, 96, 98, 101–105, 107–112, 115, 118–126, 128, 131–141, 143, 145, 147, 150, 153, 158, 160–166, 168, 169, 171, 174, 180–185, 189–191, 194, 195, 203–205, 207, 209–211, 215, 216, 220, 222, 224–232, 240, 248–253, 255, 256, 262–265, 269–272, 274, 279, 282, 283, 285–290, 292, 300–302, 309, 310, 312, 313, 315, 319, 323–327, 329, 334, 336–338, 341, 342, 344, 346, 347, 350, 352, 354, 355, 357, 358, 369, 370, 372, 373, 375–379, 381, 383–385, 387–389, 391, 393–398, 400, 402, 404, 406, 409–411, 413–415, 420, 430–433, 435, 439–442, 447, 448, 450, 452, 454, 456, 457, 459–461, 464, 465, 467–474, 477, 481, 482, 485, 488, 491–493, 496] |
| → Building/City-scale | 6 | Figure: [2] — Building/City-scale [2] — [2, 7, 233, 320, 458, 475] |
| Proximity | | |
| → Co-located | 69 | Figure: [98] — [13, 31, 33, 72, 85, 86, 98, 104, 116, 119, 125, 127, 128, 140, 157, 159, 167, 178, 190, 193, 203–205, 222, 224, 227, 243–246, 250, 258, 270, 289, 290, 300, 303, 314, 316, 324, 328, 340, 354, 355, 369, 374, 378, 379, 383, 394, 411, 416, 419, 420, 425, 429, 430, 432, 433, 435, 438, 443, 447, 451, 452, 461, 472, 473, 495] |
| → Co-located with Distance | 251 | Figure: [451] — [9–11, 14, 18, 19, 21, 24–27, 29, 30, 33, 35, 39, 42–45, 47–49, 51–53, 55, 56, 61, 63–67, 69, 71, 77–80, 82, 83–84, 94, 96, 98, 102, 103, 105, 107–112, 115, 117, 118, 120, 121, 124, 126, 130–145, 147, 150, 153, 156, 158, 160–162, 164–166, 168, 171, 174, 177, 180–183, 185, 188, 191, 194–197, 199–201, 206, 207, 209, 211, 213, 215, 220, 221, 223, 225, 226, 229–232, 239–242, 248, 251–253, 255–257, 262, 264, 271–275, 278, 282, 283, 285, 288, 292, 295, 297, 301, 302, 305, 309, 310, 312, 315, 318, 320, 323–327, 329, 333, 335–338, 341, 346–348, 350–352, 357, 358, 360–363, 366–368, 370, 372, 373, 375–377, 384, 385, 387, 389, 391, 393, 396–398, 400, 402, 404, 406–410, 412, 414, 415, 418, 431, 437, 439–443, 445, 448, 451, 454, 456–460, 464, 465, 467–471, 474, 476, 477, 479–481, 485, 487, 488, 491, 493] |
| → Semi-Remote | 19 | Figure: [114] — [15, 38, 58, 62, 76, 114, 184, 224, 227, 249, 317, 344, 381, 382, 436, 450, 475, 482, 494] |
| → Remote | 66 | Figure: [377] — [4, 12, 46, 48, 50, 54, 59, 73, 74, 84, 101, 114, 122, 123, 145, 146, 149, 163, 169, 187, 209, 210, 212, 216, 228, 233, 234, 237, 238, 252, 263, 265–269, 279, 284, 286, 287, 296, 302, 306, 313, 319, 330, 332, 334, 342, 343, 365, 371, 377, 380, 388, 395, 404, 413, 417, 479, 483, 484, 486, 489, 492, 496] |

| Category | Count | Citations | |
|--|-------|---|--|
| Section 5. Purposes and Benefits of Visual Augmentation | | | |
| Facilitate Programming | 154 | Figure: [33] — [9, 12, 18, 19, 24, 25, 27, 30, 33, 38, 42, 45, 47, 51–54, 61–63, 66, 67, 69, 72, 74, 76, 79, 80, 83, 84, 93, 94, 98, 101, 103–105, 111, 115, 118, 120–124, 126, 130–133, 135–137, 140, 142–146, 150, 153, 160–163, 169, 174, 178, 181, 184, 188, 191, 195, 196, 199–201, 206, 207, 209, 211, 212, 215, 216, 220, 227, 228, 231, 232, 239, 242, 251–253, 262, 263, 265, 267, 270, 271, 273–275, 279, 283–285, 288, 289, 295, 301, 303, 306, 312, 313, 315, 318, 319, 323–326, 329, 330, 333, 336, 341, 344, 352, 358, 366, 373, 379, 385, 387, 388, 397, 398, 400, 407, 408, 448, 454, 456, 457, 467, 468, 474, 487–489, 493, 494, 496] | |
| Support Real-time Control | 126 | Figure: [494] — [4, 13, 15, 19, 20, 25–27, 35, 39, 46, 50, 55, 58, 59, 73, 76–78, 82, 85, 86, 92, 102, 110, 114, 125, 133, 139, 146, 147, 149, 156, 157, 163, 164, 169, 171, 177, 183, 185, 187, 190, 191, 194, 203–205, 209, 212, 215, 221, 222, 224, 233, 234, 237, 238, 248, 250, 255, 256, 264, 266, 268, 269, 286, 287, 290, 296, 297, 309, 310, 314, 327, 332, 334, 342, 347, 348, 354, 355, 357, 365, 370, 371, 376, 378, 380, 381, 383, 384, 389, 394, 396, 402, 404, 407, 409–413, 417, 419, 420, 432, 435, 442, 447, 451, 452, 459–461, 469, 470, 477, 480, 482–484, 486, 491, 494, 495] | |
| Improve Safety | 32 | Figure: [326] — [21, 43, 44, 56, 64, 66, 68, 88, 104, 138, 147, 160, 182, 188, 200, 225, 252, 282, 292, 326, 352, 354, 372, 379, 385, 397, 410, 420, 432, 450, 458, 495] | |
| Communicate Intent | 82 | Figure: [372] — [21, 25, 27, 29, 33, 44, 51–54, 59, 64, 67, 69, 88, 89, 103, 104, 108, 118, 136–139, 141, 153, 160, 171, 188, 200, 211, 223, 224, 227, 241, 248, 251, 262, 267, 271, 292, 300, 305, 313, 318–320, 325, 326, 329, 342, 354, 358, 360–363, 366, 367, 372, 373, 375, 376, 387, 404, 410, 433, 439–441, 445, 450, 458, 464, 465, 473, 476, 479–481, 492, 494] | |
| Increase Expressiveness | 115 | Figure: [158] — [3, 10, 11, 14, 31, 45, 48, 49, 55, 58, 65, 71, 82, 85, 90, 91, 93, 96, 107–109, 112, 116, 117, 119, 125–128, 134, 138, 142, 158, 159, 165–168, 171, 180, 183, 189, 193, 197, 198, 210, 213, 221, 229, 230, 240, 242–246, 257, 258, 261, 272, 273, 278, 300, 302, 317, 320, 328, 332, 335, 337, 338, 340, 343, 346, 350–352, 355, 368–370, 374, 377, 382, 391, 393, 395, 401, 406, 412, 414–418, 425, 429–431, 436–438, 443, 445, 448, 451, 460, 467, 471–473, 475, 481, 485, 492] | |
| Section 6. Classification of Presented Information | | | |
| Internal Information | 94 | Figure: [66, 479] — [9, 13, 15, 18, 19, 21, 25, 30, 44, 45, 53–56, 63, 64, 66, 86, 98, 101, 104, 107, 115, 120, 124, 126, 131–133, 136–138, 144, 145, 156, 158, 160, 181, 188, 195, 196, 199, 200, 209, 220, 223, 224, 228, 229, 231, 234, 251, 253, 262, 267, 271, 282, 283, 285, 292, 302, 310, 313, 315, 324, 329, 332, 334, 340, 352, 354, 355, 366, 367, 372, 373, 375, 379, 380, 385, 387, 410, 413, 416, 443, 450, 458, 474, 479, 481, 483, 484, 487, 488] | |
| External Information | 230 | Figure: [21, 377] — [4, 10, 12, 15, 21, 24–26, 33, 35, 38, 39, 43–47, 50, 53, 54, 56, 59, 61–63, 66, 69, 71, 73, 74, 76, 77, 79, 80, 82, 84, 85, 89, 92, 94, 102, 103, 108, 110, 111, 114, 115, 119–123, 125, 131–133, 135, 136, 138–140, 143–147, 149, 150, 153, 156, 157, 161, 164–166, 169, 171, 174, 177, 178, 181, 182, 184, 185, 188, 190, 194, 196, 199–201, 205, 209, 211–213, 216, 220, 223, 224, 226–234, 237, 238, 241, 246, 248, 251–253, 255, 256, 263–269, 274, 278, 282, 283, 287–289, 292, 295–297, 301, 305, 306, 309, 310, 312, 314, 315, 318, 323, 325–327, 329, 330, 332–334, 336, 341–343, 347, 348, 352, 354, 355, 357, 358, 360–362, 367, 376–380, 383, 384, 388, 389, 396–398, 400, 402, 404, 406, 407, 409–413, 415, 416, 420, 433, 435, 439–442, 445, 448, 451, 452, 454, 456, 459–461, 464, 465, 468, 471, 477, 479–481, 483–486, 488, 489, 491–493, 495, 496] | |
| Plan and Activity | 151 | Figure: [76, 136] — [9, 12, 21, 25–27, 29, 30, 33, 35, 42–44, 51–54, 59, 62, 64, 66, 67, 69, 72–74, 76, 78, 82, 83, 88, 94, 103–105, 108, 111, 118, 121–123, 126, 130, 131, 135–141, 146, 153, 156, 160, 162, 163, 169, 177, 187, 188, 191, 194, 196, 199, 200, 206, 209, 211, 212, 215, 220, 221, 223, 226–229, 248, 252, 255, 256, 262, 263, 267, 270, 271, 275, 284–288, 290, 292, 303, 305, 306, 312, 313, 315, 318–320, 325–327, 329, 333, 336, 341, 342, 344, 354, 358, 360–363, 365–367, 371–373, 379–381, 387, 391, 400, 404, 407, 415, 416, 450, 457, 458, 467, 470, 472, 473, 476, 479–482, 488, 493–495] | |
| Supplemental Content | 117 | Figure: [8, 386] — [8, 10, 11, 14, 20, 27, 31, 45, 48, 49, 55, 58, 65, 71, 77, 85, 90, 91, 93, 96, 107–109, 112, 116, 117, 119, 125, 127, 128, 134, 142, 158, 159, 165–168, 171, 180, 183, 189, 193, 197, 203, 204, 207, 210, 222, 225, 229, 240, 242–246, 249, 250, 255, 257, 258, 272, 273, 290, 300, 302, 317, 328, 335, 337, 338, 340, 346, 350–352, 367–370, 374, 377, 382, 385, 386, 393–395, 401, 408, 412, 414–419, 425, 429–432, 436, 438, 443, 445, 447, 448, 451, 460, 472, 473, 475, 481, 485, 492] | |

| Category | Count | Citations | |
|--|-------|---|--|
| Section 7. Design Components and Strategies | | | |
| <i>UIs and Widgets</i> | | | |
| → Menus | 115 | Figure: [27, 58] — [9–12, 18, 19, 24, 25, 27, 45, 48, 51–53, 55, 58, 61–63, 65, 66, 71, 71, 79, 89, 92, 94, 96, 101, 103, 105, 112, 116, 120, 126, 131, 136, 137, 140, 144, 149, 150, 153, 156, 159, 168, 174, 181, 188, 190, 190, 194, 194–196, 196, 199, 206, 207, 215, 224, 228, 231, 233, 234, 239, 242, 253, 253, 262, 263, 269, 271, 274, 275, 278, 278, 286, 289, 292, 292, 297, 301, 301, 302, 305, 325, 326, 328, 333, 336, 338, 344, 351, 351, 357, 360, 373, 375, 377, 380, 381, 385, 387, 397, 400, 407, 410, 412, 412, 416, 420, 420, 429, 437, 443, 445, 456, 459, 469, 479, 484, 487, 488, 488, 496] | |
| → Information Panels | 80 | Figure: [15, 145] — [9, 15, 18, 44, 45, 48, 52–55, 59, 71, 86, 89, 92, 94, 96, 98, 104, 107, 112, 115, 120, 128, 136, 144, 145, 149, 156, 181, 185, 188, 190, 194–196, 199, 207, 223, 224, 228, 229, 232–234, 253, 262, 267, 278, 290, 292, 301, 315, 319, 329, 332, 336, 338, 344, 351, 355, 360, 373, 379–381, 412, 416, 420, 429, 437, 443, 451, 465, 470, 474, 479, 484, 488, 496] | |
| → Labels and Annotations | 241 | Figure: [96, 492] — [9, 11–13, 15, 18–21, 24–27, 29, 31, 33, 35, 44, 47–54, 56, 59, 61–64, 66, 67, 69, 71–73, 76, 77, 79, 80, 82, 83, 85, 88, 92, 94, 96, 98, 101, 103–105, 110, 111, 115, 118–121, 124–126, 131–133, 135–141, 143–146, 150, 153, 156–158, 161, 164, 165, 168, 174, 177, 181, 184, 188, 190, 191, 194–196, 199–201, 203, 206, 209, 211–213, 220, 223, 225–228, 231–234, 237, 238, 241, 242, 246, 249–253, 256, 262–265, 267–271, 273–275, 278, 283–285, 288–290, 292, 301–303, 305, 306, 310, 312, 313, 315, 318, 323–329, 333, 334, 336, 338, 341, 343, 347, 350, 351, 354, 358, 360–363, 366–368, 371, 373, 375–377, 380, 383, 384, 387–389, 396–398, 400, 402, 406, 407, 410, 412, 413, 416, 420, 429, 430, 433, 435, 437, 439–442, 445, 447, 450, 451, 457, 459, 464, 465, 468, 472, 477, 479–485, 487–489, 491–496] | |
| → Controls and Handles | 24 | Figure: [169, 340] — [42, 46, 58, 83, 127, 130, 159, 163, 169, 193, 201, 205, 206, 212, 225, 238, 239, 328, 330, 340, 416, 443, 469, 472] | |
| → Monitors and Displays | 47 | Figure: [171, 443] — [11, 39, 48, 54, 76, 96, 112, 131, 143, 168, 171, 190, 196, 203, 204, 213, 222, 224, 239, 253, 309, 315, 317, 332, 337, 338, 348, 355, 368, 380, 382, 391, 394, 402, 409, 418, 419, 431, 436, 443, 445, 447, 471, 472, 475, 476, 495] | |
| <i>Spatial References and Visualizations</i> | | | |
| → Points and Locations | 208 | Figure: [325, 358, 435, 451] — [9, 12, 13, 15, 18–21, 24–26, 26, 27, 29, 31, 33, 35, 35, 48, 50–54, 61, 61–63, 66, 67, 69, 71, 71, 73, 73, 74, 76, 77, 82, 83, 85, 88, 92, 94, 94, 96, 98, 101, 110, 110, 111, 118, 120, 120, 121, 121, 122, 122, 123, 123–126, 131–133, 135–137, 139, 139–141, 143–146, 146, 150, 153, 156, 156–158, 161, 161, 163, 164, 174, 177, 181, 190, 190, 191, 194, 194, 196, 199–201, 206, 212, 216, 220, 221, 226–228, 230, 231, 231–233, 233, 234, 237, 238, 241, 242, 246, 248, 248, 250–253, 253, 256, 262–264, 267, 268, 271, 274, 278, 283, 283–285, 288, 292, 301, 301–303, 303, 306, 310, 312–315, 318, 319, 323, 323–327, 327–330, 333, 333, 334, 341, 343, 344, 347, 350, 351, 354, 358, 360, 360–362, 362, 363, 371, 373, 375, 376, 376, 380, 384, 387–389, 391, 396, 396, 397, 397, 398, 400, 402, 402, 407, 410, 410, 413, 416, 420, 425, 433, 435, 439–442, 442, 445, 450, 451, 454, 456, 459, 464, 465, 468, 470, 472, 474, 477, 479–485, 487, 487, 488, 488, 489, 491, 491–496] | |
| → Paths and Trajectories | 154 | Figure: [76, 136, 206, 450, 494] — [9, 21, 25–27, 30, 33, 35, 44, 51–54, 59, 61, 62, 64, 67, 69, 71, 73–76, 83, 88, 94, 103–105, 110, 118, 120–124, 130, 131, 136–140, 146, 149, 153, 156, 157, 160–163, 169, 177, 181, 188, 190, 191, 194, 196, 199, 201, 206, 209, 211, 212, 220, 221, 223, 226–229, 231–233, 241, 248, 251–253, 256, 262, 263, 267, 268, 270, 271, 283, 290, 292, 301–303, 305, 306, 312, 313, 315, 318, 320, 323, 325–327, 329, 333, 336, 342, 344, 354, 358, 360, 360–363, 366, 367, 372, 376, 379, 380, 387, 391, 396–398, 400, 402, 407, 410, 415, 442, 445, 450, 451, 454, 456, 459, 464, 465, 468, 470, 472, 474, 477, 479–485, 487, 487, 488, 488, 489, 491, 491–496] | |
| → Areas and Boundaries | 178 | Figure: [21, 145, 182, 191] — [9, 15, 20, 21, 25, 26, 31, 35, 38, 39, 44, 47, 48, 51, 53, 56, 61–64, 68, 69, 71, 73, 74, 77, 82, 84, 89, 92, 101, 102, 105, 110, 115, 120–123, 126, 131–133, 136, 138–140, 142, 144–146, 149, 150, 153, 156, 161, 163, 164, 168, 171, 174, 177, 178, 182, 184, 188, 190, 191, 195, 196, 200, 201, 203, 206, 211, 212, 220, 221, 223, 227, 230, 231, 233, 237, 238, 242, 246, 248, 250, 252, 256, 263–269, 273, 274, 278, 282–284, 288, 289, 292, 301, 305, 306, 309, 312, 315, 318, 325–327, 332, 333, 340–343, 346, 347, 350–352, 354, 358, 360, 362, 363, 366, 367, 376, 380, 384, 385, 388, 389, 396, 402, 406, 407, 410–413, 415–417, 425, 432, 439, 440, 442, 445, 447, 451, 456, 459, 460, 465, 470, 471, 477, 483–485, 487–489, 491–493, 495, 496] | |
| → Other Visualizations | 91 | Figure: [177, 212, 282, 322] — [10, 14, 43, 45, 46, 49, 55, 58, 65, 66, 72, 78, 79, 90, 108, 114, 116, 124, 127, 128, 134, 147, 159, 165, 167, 176, 177, 180, 183, 187, 189, 193, 197, 204, 205, 210, 212, 215, 222, 224, 225, 239, 240, 243–245, 249, 257, 258, 272, 282, 286, 300, 317, 322, 330, 332, 335, 337, 338, 348, 368–370, 374, 377–379, 381–383, 394, 395, 404, 408, 411, 417–419, 429–431, 436, 438, 443, 447, 452, 457, 461, 473, 475] | |
| <i>Embedded Visual Effects</i> | | | |
| → Anthropomorphic | 22 | Figure: [3, 158, 180, 197, 242, 473] — [3, 14, 23, 51, 107, 108, 158, 165, 180, 189, 197, 198, 242, 320, 395, 401, 414, 436, 450, 472, 473, 481] | |
| → Virtual Replica | 144 | Figure: [4, 114, 163, 209, 372, 451] — [4, 12, 21, 25, 27, 30, 33, 43, 45, 47, 51–53, 59, 61, 66, 67, 69, 73, 74, 76, 80, 82–85, 92, 101–104, 110, 111, 114, 118, 120–124, 126, 130, 131, 133, 134, 137, 138, 143, 144, 146, 147, 153, 156, 160–163, 169, 174, 183, 185, 194, 195, 201, 206, 209, 211, 212, 216, 225–227, 231, 249, 251–253, 262, 265, 267, 270, 271, 273, 283, 285, 287, 290, 292, 296, 297, 301, 302, 306, 312, 313, 318, 323–327, 329, 333, 336, 341, 342, 344, 352, 354, 358, 360, 365, 372, 376, 380, 381, 388, 396–398, 400, 410, 413, 417, 437, 438, 442, 451, 454, 456, 457, 459, 460, 465, 470, 472, 474, 476, 477, 487–489, 494, 496] | |
| → Texture Mapping | 32 | Figure: [245, 308, 328, 374, 425, 429] — [20, 39, 116, 119, 127, 159, 175, 193, 222, 243–245, 250, 258, 308, 328, 340, 348, 369, 370, 374, 378, 383, 411, 425, 429, 431, 432, 447, 452, 461, 493] | |

| Category | Count | Citations |
|--------------------------------|-------|---|
| Section 8. Interactions | | |
| <i>Interactivity</i> | | |
| → Only Output | 27 | Figure: [450] – [39, 56, 64, 89, 107, 117, 134, 145, 158, 180, 197, 223, 240, 261, 282, 314, 332, 363, 372, 382, 418, 433, 436, 438, 450, 464, 481] |
| → Implicit | 11 | Figure: [458] – [38, 44, 88, 249, 258, 292, 357, 410, 414, 458, 493] |
| → Indirect | 295 | Figure: [346] – [9–12, 14, 15, 18, 19, 21, 24–27, 29–31, 33, 35, 42, 43, 45, 47–55, 58, 59, 61–63, 66, 67, 69, 71–74, 76–80, 82–86, 90–94, 96, 98, 101–103, 105, 108–112, 114, 115, 118, 120–124, 126, 130–133, 135–144, 146, 147, 149, 150, 153, 156, 158, 160–166, 168, 169, 171, 174, 177, 181–185, 188, 189, 191, 194–196, 199–201, 206, 207, 209–211, 213, 215, 216, 220, 221, 226–234, 237–239, 241–243, 248, 251–253, 255–257, 262–269, 271–275, 278, 279, 283–288, 295–297, 301–303, 305, 306, 309, 310, 312, 313, 315, 317–320, 323, 325–327, 329, 330, 332–338, 341–344, 346, 347, 350–352, 358, 360–362, 365–368, 370, 372, 373, 375–377, 380, 382, 384, 385, 387–389, 391, 393, 395–397, 400, 402, 404, 406–409, 412, 413, 415, 417, 418, 431, 436, 437, 439–443, 445, 448, 454, 456, 459–461, 465, 467–471, 474–477, 479–489, 491, 492, 494–496] |
| → Direct | 72 | Figure: [316] – [13, 20, 30, 31, 33, 46, 49, 65, 98, 104, 116, 119, 125, 127, 128, 140, 157, 159, 163, 167, 178, 187, 190, 193, 203–205, 212, 222, 224, 225, 243–246, 250, 270, 289, 290, 300, 316, 324, 328, 340, 348, 354, 355, 369, 371, 374, 378, 379, 381, 383, 394, 398, 411, 416, 419, 420, 425, 429, 430, 432, 435, 443, 447, 451, 452, 457, 472, 473] |
| <i>Interaction Modalities</i> | | |
| → Tangible | 68 | Figure: [163] – [13, 21, 31, 33, 49, 72, 82, 85, 86, 94, 98, 104, 116, 117, 124, 125, 127, 128, 138, 140, 143, 144, 159, 163, 167, 178, 190, 193, 229, 243–246, 251, 258, 270, 275, 289, 290, 303, 313, 323, 324, 328, 329, 337, 338, 340, 354, 355, 369, 374, 379, 398, 409, 414, 416, 419, 420, 425, 429, 435, 443, 448, 451, 472, 473, 489] |
| → Touch | 66 | Figure: [169] – [9, 10, 18, 19, 53, 55, 61–63, 65, 72, 76, 92, 101, 103, 130–133, 135, 136, 140, 144, 149, 153, 159, 163, 169, 195, 196, 201, 207, 209, 212, 228, 230, 231, 239, 243, 257, 263, 285, 288, 295, 300, 302, 305, 333, 346, 350, 373, 377, 382, 385, 404, 407, 416, 430, 445, 456, 459, 461, 479–481, 487] |
| → Controller | 136 | Figure: [191] – [12, 15, 20, 31, 35, 39, 42, 45, 46, 48–50, 54, 71, 73, 74, 77, 83, 84, 90, 96, 101, 102, 105, 110, 115, 119–123, 142, 146, 147, 149, 150, 156, 157, 160, 164, 171, 177, 185, 187, 188, 191, 203–205, 210, 215, 220–222, 224, 227, 228, 233, 234, 250, 252, 253, 256, 264, 266–269, 275, 279, 284, 286, 306, 309, 310, 312, 313, 315, 317–319, 330, 332–335, 338, 341, 343, 344, 347, 348, 351, 365, 370–372, 378, 380, 381, 383, 384, 388, 389, 391, 394, 395, 402, 411, 413, 415, 417, 418, 432, 433, 436, 442, 443, 447, 451, 452, 457, 460, 467, 468, 470, 475, 476, 483–486, 491–493, 495] |
| → Gesture | 116 | Figure: [58] – [3, 11, 24–27, 30, 33, 43, 47, 48, 51, 52, 58, 59, 66, 69, 78, 80, 91, 93, 96, 98, 103, 105, 109, 111, 112, 114, 118, 126, 136, 137, 139, 141, 156, 158, 161, 162, 165, 166, 168, 174, 181–183, 189, 194, 199, 200, 206, 211, 216, 225, 231, 232, 237, 238, 242, 255, 257, 262, 270–274, 278, 285, 287, 296, 297, 301, 302, 320, 325–327, 329, 332, 336, 337, 341, 342, 352, 357, 358, 360, 362, 366, 368, 372, 375, 376, 387, 393, 396, 397, 400, 401, 410, 412, 431, 437, 439–441, 454, 465, 469, 474, 477, 488, 494, 496] |
| → Gaze | 14 | Figure: [482] – [27, 28, 33, 38, 67, 114, 262, 300, 320, 325, 336, 358, 362, 482] |
| → Voice | 18 | Figure: [184] – [14, 27, 54, 67, 108, 156, 182, 184, 197, 213, 239, 336, 354, 362, 367, 396, 404, 406] |
| → Proximity | 21 | Figure: [200] – [14, 44, 88, 138, 182, 200, 229, 241, 265, 283, 292, 305, 350, 361, 368, 430, 431, 437, 458, 467, 471] |

| Category | Count | Citations |
|---------------------------------------|-------|---|
| Section 9. Application Domains | | |
| Domestic and Everyday Use | 35 | Figure: [263] — <i>Household Task</i> authoring home automation [53, 111, 135, 163, 177, 191, 212, 228, 263, 327, 365, 387, 480], item movement and delivery [76, 108, 209, 265], displaying cartoon-art while sweeping [481], multi-purpose table [430] <i>Photography</i> drone photography [114, 171], <i>Advertisement</i> mid-air advertisement [317, 382, 418, 475] <i>Wearable Interactive Devices</i> haptic interaction [443], fog screens [418], head-worn projector for sharable AR scenes [168] <i>Assistance and companionship</i> elder care [65], personal assistant [239, 367, 368] <i>Tour and exhibition guide</i> tour guide [58, 295], museum exhibition guide [168, 368], guiding crowds [475], indoor building guide [89], museum interactive display [112] |
| Industry | 166 | Figure: [21] — <i>Manufacturing and Assembly</i> joint assembly and manufacturing [21, 30, 43, 44, 80, 138–140, 161, 194, 231, 274, 283, 289, 297, 327, 366, 376, 396, 397, 410, 435, 454, 456, 493], grasping and manipulation [24–27, 33, 59, 67, 79, 132, 133, 137, 150, 153, 169, 185, 216, 226, 248, 255, 336, 342, 358, 379, 402], joint warehouse management [200], taping [105], tutorial and simulation [52], welding [303, 313, 413] <i>Maintenance</i> maintenance of robots [144, 162, 252, 253, 285, 292, 302, 375], remote collaborative repair [31, 48, 74, 477], performance evaluation and monitoring [98, 103, 126, 128, 492], setup and calibration [61, 94, 120–123, 301, 306, 319, 323, 333, 352, 398, 487, 488], debugging [373] <i>Safety and Inspection</i> nuclear detection [15, 234], drone monitoring [76, 114, 171, 184, 227, 332, 482, 494], safety feature [21, 44, 56, 66, 104, 160, 182, 282, 292, 372, 379, 385, 450], cartoon-art warning [481], collaborative monitoring [363], ground monitoring [50, 73, 146, 211, 269, 380, 479, 484] <i>Automation and Teleoperation</i> interactive programming interface [9, 12, 45, 47, 51, 62, 63, 66, 69, 93, 101, 104, 118, 124, 130, 131, 136, 143, 174, 177, 184, 188, 195, 201, 206, 207, 211, 212, 220, 227, 232, 251, 262, 270, 271, 284, 287, 288, 312, 315, 318, 324–326, 329, 385, 400, 407, 468, 474, 496] <i>Logistics</i> package delivery [265] <i>Aerospace</i> surface exploration [54], teleoperated manipulator [310], spacecraft maintenance [470] |
| Entertainment | 32 | Figure: [350] — <i>Games</i> interactive treasure protection game [350], pong-like game [346, 370], labyrinth game [258], tangible game [49, 178, 230, 273], educational game [412], air hockey [91, 451], tank battle [90, 221], adventure game [55], role-play game [229], checker [242], domino [246], ball target throwing game [337], multiplayer game [115, 404], virtual playground [272] <i>Storytelling</i> immersive storytelling [328, 369, 395, 415, 467] <i>Enhanced Display</i> immersive gaming and digital media [431] <i>Music</i> animated piano key press [472, 473], tangible tabletop music mixer [340] <i>Festivals</i> festival greetings [382] <i>Aquarium</i> robotic and virtual fish [240] |
| Education and Training | 22 | Figure: [445] — <i>Remote Teaching</i> remote live instruction [445] <i>Training</i> military training for working with robot teammates [199, 360, 362], piano instruction [472, 473], robotic environment setup [142], robot assembly guide [18], driving review [11, 213], posture analysis and correction [183, 437] <i>Tangible Learning</i> group activity [71, 275, 328, 337, 408, 412, 467], programming education [278, 416], educational tool [351] |
| Social Interaction | 21 | Figure [108] — <i>Human-Robot Social Interaction</i> reaction to human behaviors [93, 108, 109, 375, 406, 414], cartoon-art expression [377, 481], human-like robot head [14], co-eating [134], teamwork [404], robots with virtual human-like body parts [158, 165, 180], trust building [141], task assignment by robot [439–441, 465] <i>Robot-Assisted Social Interaction</i> projected text message conversations [382] <i>Inter-Robot Interaction</i> human-like robot interaction [107] |
| Design and Creative Tasks | 11 | Figure: [476] — <i>Fabrication</i> augmented 3D printer [476], interactive 3D modelling [341], augmented laser cutter [304], design simulation [52] and evaluation [393] <i>Design Tools</i> circuit design guide [445], robotic debugging interface [145], design and annotation tool [96], augmenting physical 3D objects [210] <i>Theatre</i> children's play [10, 166] |
| Medical and Health | 36 | Figure: [354] — <i>Medical Assistance</i> robotic-assisted surgery [13, 35, 77, 82, 84, 85, 92, 110, 125, 147, 164, 181, 190, 256, 264, 290, 309, 347, 354, 355, 384, 389, 409, 419, 420, 442, 459, 460, 485, 491], doctors doing hospital rounds [228], denture preparation rounds [196] <i>Accessibility</i> robotic prostheses [86, 136] <i>Rehabilitation</i> autism rehabilitation [29], walking support [334] |
| Remote Collaboration | 6 | Figure: [242] — <i>Remote Physical Synchronization</i> physical manipulation by virtual avatar [242] <i>Avatar enhancement</i> life-sized avatar [197], floating avatar [436, 475], life-sized avatar and surrounding objects [189] <i>Human-like embodiment</i> traffic police [149] |
| Mobility and Transportation | 13 | Figure: [7] — <i>Human-vehicle interaction</i> projected guidance [2, 7], interaction with pedestrians [64, 88, 320], display for passengers [223] <i>Augmented Wheelchair</i> projecting intentions [458], displaying virtual hands to convey intentions [300], self-navigating wheelchair [314], assistive features [495] <i>Navigation</i> tangible 3D map [258], automobile navigation [438] |
| Search and Rescue | 35 | Figure: [363] — <i>Ground search</i> collaborative ground search [296, 343, 360, 362, 363], target detection and notification [211, 241, 266, 269, 305, 361, 468, 479], teleoperated ground search [54, 73, 102, 146, 156, 234, 257, 238, 267, 268, 365, 380, 417, 469, 483, 484, 486] <i>Aerial search</i> drone-assisted search and rescue [114, 332, 482], target detection and highlight [464] <i>Marine search</i> teleoperated underwater search [233] |
| Workspace | 9 | Figure: [159] — <i>Adaptive Workspaces</i> individual and collaborative workspace transformation [159, 430, 431] <i>Supporting Workers</i> reducing workload for industrial robot programmers [407], mobile presentation [168, 257, 338], multitasking with reduced head turns [38], virtual object manipulation [357] |
| Data Physicalization | 12 | <i>Physical Data Encoding</i> physical bar charts [167, 429], embedded physical 3D bar charts [425] <i>Scientific Physicalization</i> mathematical visualization [127, 243], terrain visualization [116, 117, 243–245, 308], medical data visualization [243], <i>Physicalizing Digital Content</i> handheld shape-changing display [258, 374] |

Section 10. Evaluation Strategies

| | | |
|-----------------|-----|---|
| Demonstration | 97 | Workshop [44, 45, 167, 244, 246, 274, 476], Theoretical Framework [200, 374], Example Applications [30, 47, 66, 84, 124, 127, 142, 145, 159, 174, 195, 197, 209, 210, 243, 245, 252, 265, 269, 315, 325, 341, 342, 366, 368, 382, 385, 418, 425, 431, 476, 481, 483, 496], Focus Groups [272, 467], Early Demonstrations [24, 49, 53, 55, 82, 89, 96, 102, 104, 111, 115, 117, 136, 149, 162, 199, 216, 221, 239–241, 251, 255, 257, 270, 290, 305, 338, 346, 370, 375, 387, 400, 404, 408, 414, 436, 451, 479], Case Studies [65, 105, 189, 288, 324, 329], Conceptual [9, 220, 230, 271, 367, 472, 492] |
| Technical | 83 | Time [21, 48, 51, 59, 67, 69, 112, 126, 165, 171, 227, 284, 318, 358, 406, 417, 464, 486, 495], Accuracy [14, 15, 29, 58, 59, 64, 76, 84, 90, 101, 112, 124, 131, 150, 153, 165, 171, 181, 184, 226, 229, 232, 312, 317, 318, 320, 460, 464, 482, 486], System Performance [38, 59, 62, 63, 79, 91, 93, 118, 125, 128, 130–132, 143, 168, 211, 282, 285, 302, 313, 319, 332, 334–336, 352, 355, 361, 363, 406, 468, 470], Success Rate [262, 314] |
| User Evaluation | 122 | NASA TLX [15, 27, 33, 43, 63, 67, 69, 76, 112, 114, 125, 133, 160, 201, 226, 340, 358, 372, 377, 407], Interviews [64, 103, 114, 140, 158, 191, 369, 435, 443], Questionnaires [11, 18, 25, 31, 48, 59, 98, 132, 134, 138, 150, 160, 169, 182, 183, 193, 223, 242, 267, 275, 300, 350, 373, 377, 393, 416, 417, 430, 445, 464, 495], Lab Study with Users [12, 56, 169, 188, 328, 379, 415, 473], Qualitative Study [13, 21, 25, 52, 54, 138, 158, 163, 165, 263, 266, 289, 357, 429, 437, 438, 443, 494], Quantitative Study [11, 13, 19, 25, 38, 43, 54, 76, 85, 86, 107, 108, 111, 138, 140, 141, 165, 171, 180, 184, 193, 266, 289, 328, 357, 439, 448, 494], Lab Study with Experts [10, 116, 340], Observational [58, 135, 258, 369, 382], User Feedback [135, 448] |