Augmented Robotic Telepresence (ART): A Prototype for Enhancing Remote Interaction and Participation

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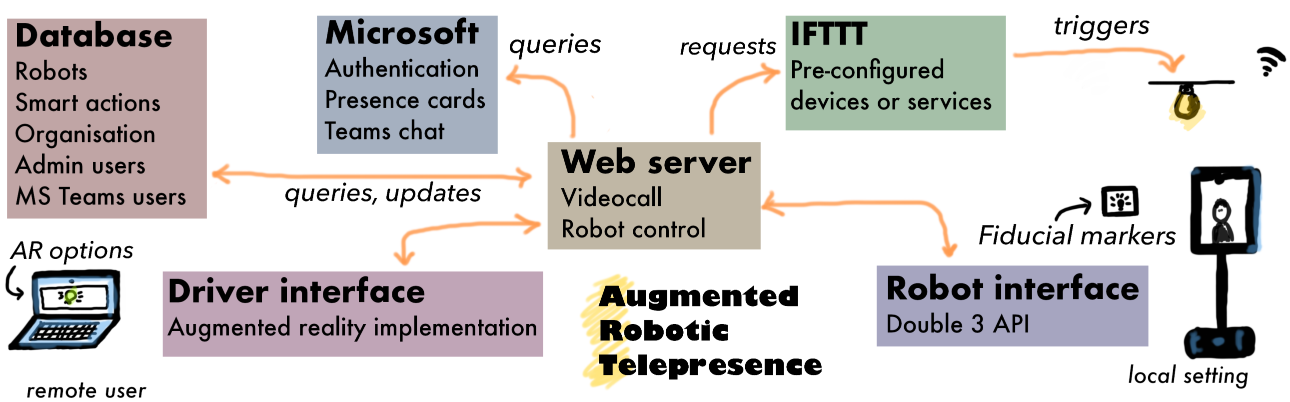

Figure 1: ART prototype. Overview of components and functionality.

ABSTRACT

Mobile robotic telepresence (MRP) allows remote users' access and mobility in a range of local environments. MRP devices have been adopted in societally significant domains such as workplaces, museums, commerce, education, and healthcare, especially during the Covid-19 pandemic to provide accessibility to these spaces when physical attendance was precluded. Although telepresence robots have autonomous systems features such as collision avoidance, they do not typically allow for physical manipulation of the environment, so they have been found to engender limited trustworthiness and have yet to achieve widespread adoption. This work presents a prototype exploring the potential of Augmented Robotic Telepresence (ART) to improve on inclusion, accessibility, and independence provided to remote users of MRP, broadening the space for interaction and participation, by augmenting affordances in the local environment via techniques such as Augmented Reality (AR), Internet of Things (IoT), and remote actuation. Herein we describe the ART prototype developed thus far, which is built on top of a commercial MRP robot, the Double 3 by Double Robotics; we elaborate on the ART prototype design, its implementation, and current capabilities. Lastly, we describe our research plans, including design workshops with museum stakeholders, and point towards directions for future work.

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CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; *Ubiquitous and mobile computing systems and tools*; *Participatory design.*

KEYWORDS

mobile robotic telepresence, human robot interaction, augmented reality, hybrid interaction, remote user

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1 MOTIVATION AND CONTEXT

Mobile robotic telepresence (MRP) allows remote users' access and mobility in local environments. Its applications range from hazardous environments [22], to conferences [23], offices [30], museums [24], and homes [14]. MRP thus allows visiting (and moving in) places without the need to travel and being physically present.

Current off-the-shelf MRP devices routinely include AI-based features such as obstacle avoidance, indoor positioning, waypoint navigation (route planning) [4], which may be characterised as 'technological autonomy'. However, there are a range of functional limitations of MRP (e.g., due to limited cameras, microphones, and lack of physical actuators), these have been shown to affect the usability and thereby overall trustworthiness and adoption of MRP [18, 28–30].

Similar to the challenges encountered in more traditional mediums of hybrid interaction, such as videoconferencing platforms, asymmetries between MRP local and remote users arise, often unfavourably impacting the remote users' experiences and leading to their exclusion from participation [21, 26, 27]. For instance, remote users are negatively perceived when MRP systems disrupt existing social norms and display unwanted behaviours, even when not under their control (e.g. interrupting others due to technical failures) [18]. In addition, the autonomous behaviour of the robot is not easily interpreted by users due to lack of display capabilities to make it apparent to both the local and remote users what the MRP is doing from moment-to-moment. Therefore, remote users frequently rely on co-present people to provide assistance with navigation, object handling, and even hearing and seeing (e.g., reading text) in the local environment [12]. Contrasting views from remote users about relying on local users' assistance have been reported; some people have expressed disliking feeling helpless and others embraced the MRP system constraints [24]. Nonetheless, more work is needed to both improve remote users' autonomy and facilitate how they request and receive help.

While MRP systems enable remote users to assert a physical presence in the location and provide them with the extended freedom to move around and explore, they lack the required affordances for physical autonomy and social presence; for instance, they provide limited identity (e.g. recognising who is driving the MRP) expressiveness (e.g. drawing attention towards something in the local space), and physical capabilities (e.g. the ability to open doors)[17]. Therefore, there are several areas of opportunity where MRP systems can be extended to give remote users the means to meaningfully participate in local interaction, rather than focusing on replicating in-person interaction [13].

Others have begun to explore the potential to extend the existing capabilities of off-the-shelf MRP systems using commercial technologies such as Augmented Reality (AR), Virtual Reality (VR) and 360° video, while respecifying the design focus (e.g. to facilitate *belonging* to the local setting instead of merely imitating *being in* it)[17]. This project builds on the potential of MRP to facilitate inclusion, accessibility, and independence for telepresent users, by developing what we call the Augmented Robotic Telepresence (ART) system, to allow telepresent users to interact with the local environment and provide them with more opportunities for remote action and participation. To do this, the ART prototype draws on AR, Internet of Things (IoT) technologies, and remote actuation, aiming to tackle the technical and practical limitations that current off-the-shelf MRP systems have. In the following we describe the ART prototype developed thus far, which is built on top of a commercial MRP robot, the Double 3 by Double Robotics; we elaborate on the ART prototype design, its implementation, and current capabilities. Furthermore, we describe our research plans for engaging in co-design activities with potential remote and local users of the ART in the museum context.

2 THE ART SYSTEM

The ART is a prototype built on top of a commercial mobile telepresence robot, the Double 3 by Double Robotics [4]; it allows users to remotely move around an environment whilst conducting a video call, giving them a physical presence in the space and greater control than traditional video conferencing.

The ART draws on AR, IoT, and remote actuation to provide remote users with extended options for interacting with the environment, such as controlling smart devices and triggering actions in physical or digital spaces. The ART aims to broaden the feature offering of the Double 3, beyond simple video calls and remote navigation in the local space, into the realm of teleoperation allowing remote collaborators to act in and interact with the setting (e.g. turning lights, calling the lift, 'knocking on' doors). Teleoperation options appear on marker-based AR to the remote user on the driver interface. That is, systems administrators can upload unique fiducial markers (i.e. QR codes) and associated AR graphics which are appropriate for the particular smart action (e.g., a lightbulb for turning lights on and off). The fiducial markers can be placed in the environment, ideally on intuitive and adequate areas (e.g. next to a switch, at the robot's camera height). Figure 2 shows examples of fiducial markers. When the Double 3 comes across a fiducial marker, its associated AR graphical element will appear on the driver interface. Remote users, then, can click on the AR elements and trigger the appropriate external service which interacts with the IoT, as pre-configured by the system administrator.

Herein we provide a technical description of the ART and its additional features. Moreover, this section critically analyses the process of developing additional functionality for the Double 3, which is a platform with seemingly zero third-party, open-source

Figure 2: Fiducial markers placed in the environment: a lightbulb icon next to a switch, and a unique code outside an office

developer precedent beyond the tools and support offered by Double Robotics.

2.1 Functionality

The ART system can be used by two types of users (i.e., drivers and administrators) via a web platform. The ART platform allows administrators to add and delete Double 3 robots to the system, enable additional pre-defined features, and generate new smart actions which the drivers of the robots can utilise. Figure 3 shows a screenshot of the driver interface; the ART features are described next.

2.1.1 Pre-defined features. The standard functionality of a Double 3 robot is present in the ART system, through the utilisation of the Double Robotics SDK. Therefore, remote users can videocall and navigate in the local space, both manually (i.e., moving the MRP with the keyboard arrows) or semi-autonomously (i.e., clicking on the floor where the MRP will move on its own). The ART also provides the standard robotic actuation features present in the Double 3, such as deploying the kickstand to park the robot, raising and lowering the robot head, and redocking the robot to recharge.

In addition, the ART system implements two more features that expand on the current capabilities of the Double 3: a rear-view camera and a physical raising hand. The web platform allows system administrators to enable these optional features when adding a new robot to the system. With additional camera hardware, a rear-view can be given to remote users, which aims to increase their spatial awareness and improve the driving experience. Nonetheless, technical limitations are still present when additional cameras are connected to the Double 3, which we discuss in 2.2.4. Furthermore, a 'raise hand' button can be used in the remote user interface to trigger an IFTTT event (as explained in the next section), intended to actuate a physical device attached to the robot which will draw attention to the remote user, for instance in meetings or busy spaces. A laminated paper hand is attached to a SwitchBot bot [8], an off-the-shelf IoT solution attached to the robot, which moves when triggered by the remote user on the web platform. Figure 4 shows the ART prototype's additional features.

2.1.2 Smart actions. A smart action, in the context of this project, is an AR interaction facilitated by a fiducial marker and made by a driver which triggers IoT service(s) and/or device(s) via IFTTT middleware [6]. For example, a driver may turn on a smart lightbulb by interacting with a marker next to a light switch. IFTTT ("if this, then that") is a software platform that integrates a range of apps, devices, and services, allowing a combination of triggers and actions that can be configured to create automations or 'applets'. Given that the services available through IFTTT are vast[1], the ART prototype is a modular solution offering a range of customisation options to the system administrators.

2.1.3 MS Teams Integration. The ART system uses Microsoft infrastructure for account management, profile integration (e.g., display pictures), and Teams features. A Microsoft Organisation needs to be defined in the ART database. Currently, each deployment of the system works with one Microsoft Organisation at a time (and its instantiated robots, smart actions, etc.). Any Microsoft account within the defined Organisation can login and use the system to drive robots, and any driver user can be defined as administrator in the ART database. First-time users are required to allow certain data access permissions.

Fiducial markers can be linked to AR presence cards that allow the remote user to see, for instance, who an office or desk belongs to, their profile picture, their status on Teams, and to send them a message seamlessly in-interface. This operates within the organisation the project is set up with. Figure 5 illustrates the Microsoft integration within the ART system.

2.2 Technical Description

This section provides an overview of the technical components that comprise the ART system, including the server, the database, the driver-side interface, and the robot-side interface. Figure 1 illustrates the ART system components.

2.2.1 Server and Database. The server is a Node.js application [1]. It uses Express [5] as a web framework and Socket.io [7] for real-time communication. It operates exclusively via the server.js file, and follows the routing/configuration advice of Express and Socket.io. In addition to standard web server function, it executes all Microsoft communication using the required queries, and sends web requests to IFTTT for smart actions. All the robot control and status messaging passes through the server to either the driver or robot in question. The database stores robot configurations, smart actions, and organisation and administrators details. Drivers' data is not stored in the database, as the user data is polled from Microsoft Graph [19]. When setting up a smart action in the system, administrators can enter an IFTTT webhook (generated on the IFTTT website or app), which will be stored in the database and will trigger the specified external service or IoT action. The external hardware and/or services must be set up and confirmed working via the supplied proprietary communication (such as the TpLink

[1]See https://ifttt.com/explore/services

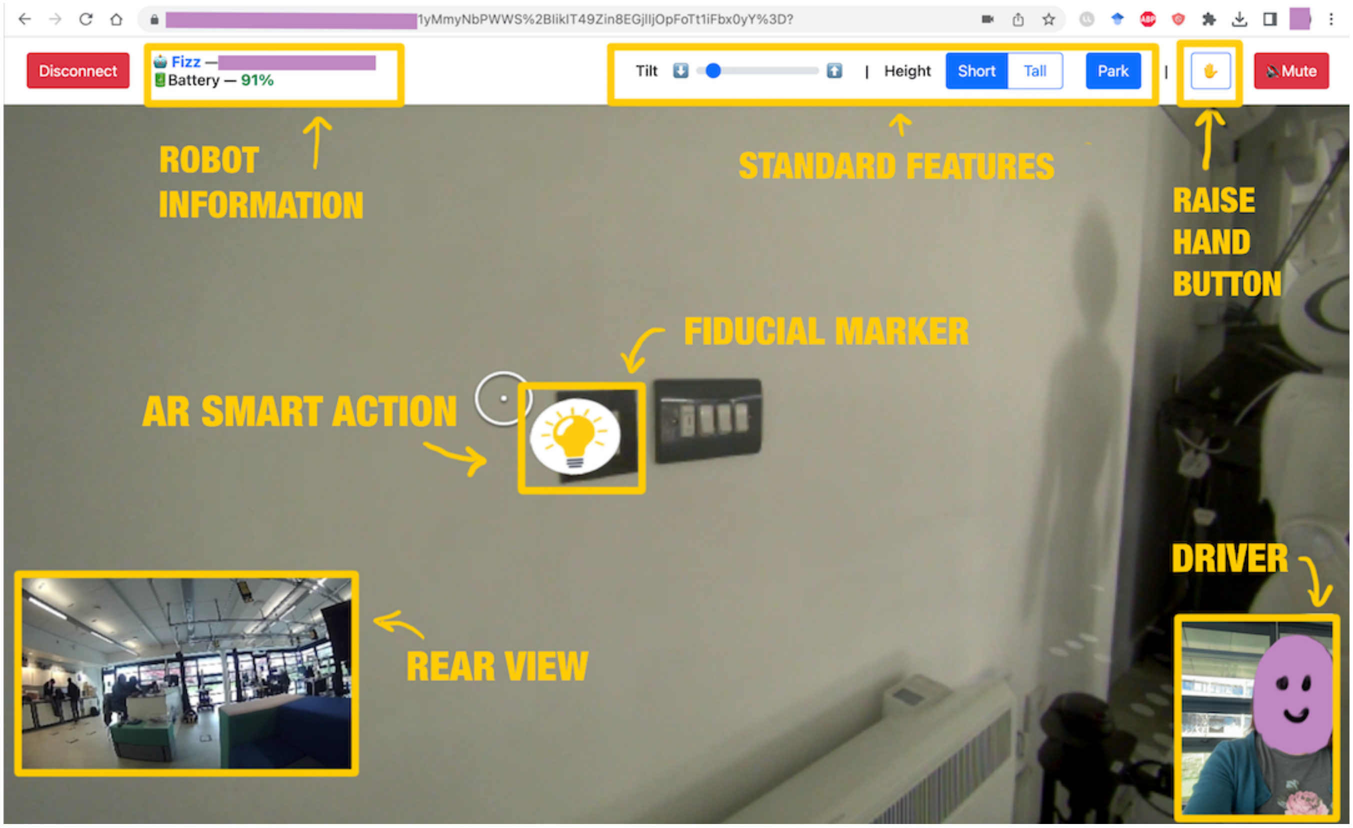

Figure 3: Screenshot of remote user interface. A smart action is displayed on the view.

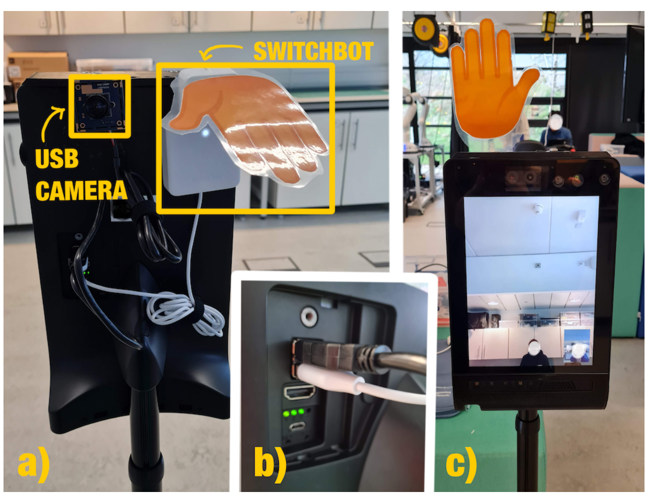

Figure 4: ART's additional features (rear camera and hand raising); a) View from the back, b) Double 3 ports, c) Hand raised, front view.

Kasa app [3], for smart bulbs), before attempting to configure them on the IFTTT website or app and the ART platform.

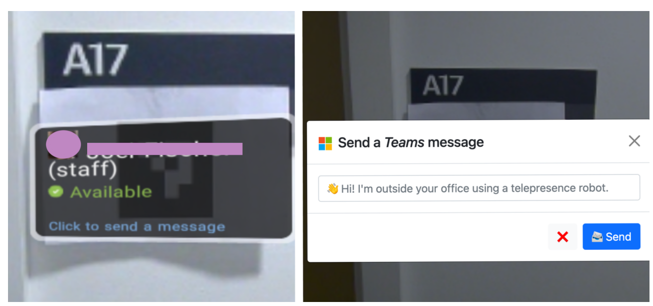

Figure 5: Microsoft integration: presence card and Teams message

2.2.2 Driver-side Interface. The driver frontend is where the majority of the project's novel functionality is either implemented or triggered by contacting the server. This is primarily due to performance and bandwidth considerations in the context of the Double 3 hardware. The novel augmented reality is implemented using AR.js [2] for fiducial marker recognition and tracking, and THREE.js [10] for 3D rendering on a HTML5 canvas. THREEx.artoolkit [11] is used as a middleman between the two libraries to translate the tracking data from AR.js into rendering data (e.g., matrices) for THREE.js. Finally, THREEMeshUI [9] is used for the presence cards feature to massively simplify rendering dynamic text. The pre-existing

Double 3 augmented reality is processed internally on-robot, and layered on top of the camera view passed to the browser. Via the aforementioned AR framework, admin-defined smart actions will appear in the driver interface when a certain fiducial marker is detected, and interacting with it will despatch a message to the server. The server will then poll the IFTTT Webhook service via a normal GET web request to trigger an applet. Likewise, when a driver initiates a connection with a robot, the driver interface polls the server to poll Microsoft Graph [19] for each active presence card. The server then responds with the name, profile picture, and activity of each of these users which is built into a 'card' using THREEMeshUI [9]. Sending a message also despatches a Socket.io command to the server, which in turn POSTs data to Microsoft Graph.

2.2.3 Robot-side Interface. The robot-side interface is intentionally 'primitive' due to hardware limitations, and meaningfully only does two things: handles its side of the video call, and interfaces with the Double 3 API. Most additive functionality, such as Microsoft Graph [19] communication and the associated augmented reality, are implemented server-side and driver-side respectively. All access to Double 3 hardware - for driving, the camera, microphone, retrieving battery percentage, etc. - is managed through the DRDoubleSDK library [25].

2.2.4 Limitations. These have been identified either as a result of the implementation itself or the limitations of the Double 3 hardware and software. Firstly, the added functionality of the ART prototype increases the processing load of the Double 3, which consequently reduces its battery life. External development using the Double 3 relies entirely on the company's developer documentation and tools, as the platform is still too niche for a wider community to form. A number of problems were encountered in the development process which could not be straightforwardly overcome, and were usually worked around, or stopped a feature in its tracks entirely. For instance, dead commands, lack of directional sound despite the 6-microphone array, and wider instability of sensor calibration and spawning.

3 FUTURE WORK

In this paper, we have presented ART, a prototype aiming to improve on inclusion, accessibility, and independence provided to remote users of MRP systems, by providing them with more opportunities for remote action and participation. It is worth remarking that, although the ART features, as described in 2.1, are not fully ready for deployment in real settings, the prototype can be used as proof-of-concept in research activities and as a baseline for further development.

Given that telepresence robots were successfully adopted in museum settings during the Covid-19 lockdowns, providing remote access to visitors (e.g., [20]), our next steps include conducting research activities with the ART prototype in the museum context. Drawing on the need for involving stakeholders and the public in the development of research projects to meet their needs and expectations, as per the public engagement agenda of Responsible Research and Innovation (RRI) frameworks [15], we are currently planning to use the ART prototype in co-design workshops with museum stakeholders. The ART will be demoed and used for prompting reflections, ideation and co-creation. The objective is to discuss and explore the feasibility and design opportunities of using Augmented Robotic Telepresence in museums, identifying needs and requirements to be considered in future work. Furthermore, it is important to engage in socially inclusive and responsible co-creation; we will reflect on our engagement methods, participants, power relations and outcomes (e.g., by using RRI co-creation toolkits such as [16]).

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