Proc. of the 9th Intl. Conf. of Asian Society for Precision Engg. and Nanotechnology (ASPEN 2022)
15–18 November 2022, Singapore. Edited by Nai Mui Ling Sharon and A. Senthil Kumar
doi://10.3850/978-981-18-6021-8_OR-18-0303

# A Mixed Reality Platform for Online Motion Planning of Mobile Robots via Hololens 2

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KEYWORDS: Mobile Robots, Mixed Reality, Motion Planning, Human-Robot Interaction

*Mobile robots have been widely used to perform a variety of tasks such as exploration or transportation of payloads within a cluttered environment. While a great deal of progress had been made towards developing autonomous motion planning capability for such robots, they still suffer from requiring significant tuning and getting into a trapped situation during navigation. Here, we proposed a hybrid alternative approach, where humans collaborate with the robots during the motion planning process to effectively achieve their task goals. In this paper, a mixed reality-based human-robot interaction platform via Hololens 2 is developed for such purpose, to tap into human knowledge-based reasoning during the global motion planning process while allowing the robot to autonomously navigate around obstacles locally. We presented the methodology and framework of our mixed reality platform and tested its performance for online human-directed motion planning on a Ghost Vision 60 quadruped robot.*

**NOMENCLATURE**

MR = Mixed Reality
HRI = Human-Robot Interaction
ROS = Robot Operating System

## 1. Introduction

Motion planning and obstacle avoidance are one of the most important challenges for autonomous mobile robots. In a dynamic and narrow environment with the presence of movable objects such as humans or other robots, sending the robot to a fixed goal could lead to a livelock situation where the robot repeatedly tries to reach the goal but takes a long time and eventually fails. Human presence in the same environment is required to understand the situation, decide, and send a command to troubleshoot the issue. In a multi-room indoor environment covering a large area beyond human proximity, it is not always ideal for the human to be present at various locations to give feedbacks.

Robot autonomous navigation requires sensors such as lidar and depth cameras to digitize and model the environment into spatial context for the input of path planning and obstacle avoidance. Digital representation of the environment captures the spatial information of the map layout and objects of interest. The advantages of using mixed reality (MR) human-robot interface (HRI) are the ability to simultaneously observe the physical and the digital worlds and interact or send commands to robots through the holograms and MR controls (1). Sharing of the common coordinate systems among the robots and MR devices is essential for localization and the creation of a cyber-physical system on different platforms.

The MR HRI systems has been developed and used for implementation in various scenarios. Humans—wearing an MR headset such as HoloLens—and robots can collaborate in the shared space for path planning (1, 2) and robot manipulator trajectory planning (3). While these systems provide advantages of handsfree and immersive MR experience, the HoloLens user does not have access to the spatial information of the map layout. Delmerico et al (1) described a scenario where HoloLens depth camera was used to observe the environment for meshed map generation and the occupancy grid representation of the map was processed offline and shared with the robots for navigation. The offline map processing defeats the propose of real-time human-robot collaboration. Ostanin et al (4) reported the online sharing of point cloud map from HoloLens to robots. However, it was for HoloLens and robot's map localization purpose and there was no map visualization on the MR interface. Moreover, since the environment was mapped by the HoloLens user, the map coverage must be accessible and safely reachable by humans. Researchers presented a framework using robots exploration to unveil the unknown indoor map layout to the

HoloLens user in real-time with the map overlaid on the physical world (5, 6). Despite the potential for online robot motion planning on the digital map via the MR interface, it cannot overcome the HoloLens' limitation which the accuracy of the far interaction inversely correlates to the distance from the HoloLens user. Chandan et al (7) introduced a beyond-proximity HRI platform using augmented reality (AR) through interaction on the computer and mobile devices which allows human to collaborate with robots those are in the other parts of the building. However, the non-MR interface is less intuitive and mobile.

This work is motivated by the need for an online motion planning system for mobile robots where humans can visualize and control robots from a vantage view covering the entire map, not obstructed by obstacles, and not limited by the range of the map. Here, we propose an MR mini map interface for the online motion planning application running on HoloLens 2. The advantage of our proposed approach allows HoloLens users to visualize, strategically plan and modify the mission for any robots in the network from a distance. The mini map MR interface improves the usability of HoloLens on interaction with far objects which are inconvenient to interact with accuracy if the object is beyond proximity. In this paper, we describe how we built the mini map MR interface on HoloLens for online robot motion planning.

## 2. Concept of Online Motion Planning

The concept of MR interaction for online motion planning through holographic mini map is that the user has a comprehensive view of the entire environment—conceptually as large as the robot navigation can cover—and is able to command robots that are out of reach from anywhere. The HoloLens user has the mobility to move around to execute human missions concurrently or the user can choose to remain stationary in a safe place while sending commands to the robots. Fig. 1A illustrates the interaction with the waypoint cursor which its pose will be sent to the robot's move base goal for execution. A sequence of the planned path of two goals is shown in Fig. 1B. The HoloLens user can plan and modify the robot's missions independently of the robot's own navigation module. In one of our tested scenarios, when a robot encountered a livelock during navigation on a busy narrow corridor, the human troubleshot the livelock by sending a move base goal through mini map MR interface, which the robot resumed its navigation afterward.

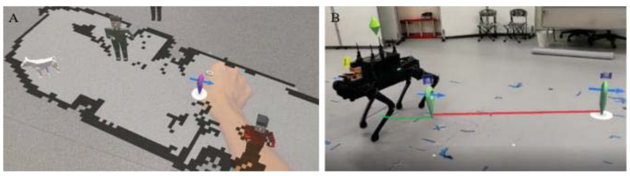


Fig. 1 (A) Concept of our mobile robot path planning through MR interface on the mini map. (B) Planned path of multiple goals.

## 3. System Overview

HoloLens runs an MR application that is built using the Unity 3D engine—a game engine used to develop a wide range of products from games to mixed reality. Interactions such as hand tracking and prebuilt MR interface are available from Microsoft Mixed Reality Toolkit (MRTK) (8). The cross-platform communication between Unity and ROS frameworks on HoloLens and robots, respectively, is managed by ROS# (9). Ghost Vision 60 quadruped robot is equipped with a companion Intel NUC running Ubuntu 18.04 and ROS Melodic. ROS topics are shared among devices in the local mesh network running ROS framework using multimaster_fkie (10). ROS topics those are published to and subscribed from the Unity framework are managed by ROS Bridge (11). The software framework is illustrated in Fig. 2.

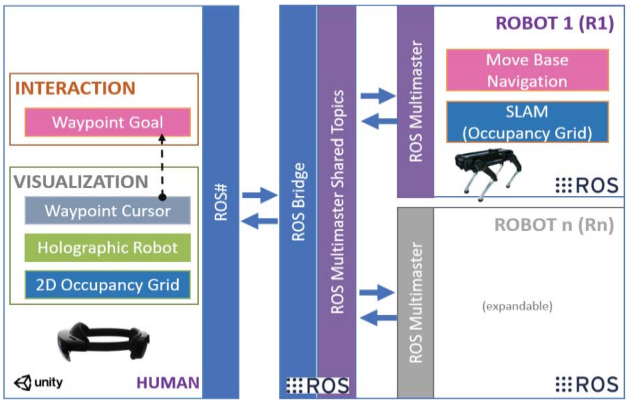


Fig. 2 The software framework of our mixed reality human-robot interaction system for visualization and interaction.

### 3.1 Mini Map Digital Twin

On the HoloLens MR application, the mini map displays online spatial information of 2D occupancy grid map, robot avatar, designated waypoint goals, and planned path—which has established relative coordinate frames and is readily available on ROS environment—in Unity environment. Unity 3D engine follows the relative coordinate frame convention in ROS to create the same spatial hierarchy as shown in Fig. 3. The global map in ROS environment is the static common coordinate reference, which Unity refers to as the origin of the invisible map board. All other Unity game objects—the children objects of the map board—have their transform values subscribed from or published to ROS via ROS# and ROS Bridge to keep both environments synchronized in real-time. With this game object hierarchy setup, the map board is movable and scalable in the MR interface, while maintaining the relative spatial information of the children's holograms on the board to keep the spatial representation of the physical world accurate. The HoloLens user can walk about and choose to have the map tag along within the user's field of view or leave the map fixed in one place. The ability to scale, move and rotate the mini map allows HoloLens users to observe the whole map area at a glance or zoom in for a closer inspection of a certain region.

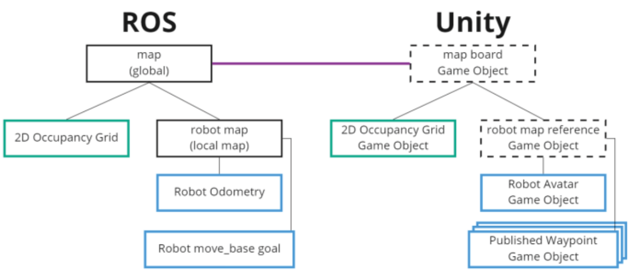


Fig. 3 The relative coordinate frames in ROS are preserved in Unity environments for accurate digital twin representation on the mini map. Unity game objects in dashed box are invisible.

### 3.2 Occupancy Grid Rendering

The 2D occupancy grid ROS message (12) contains a 1D array which represents the occupancy probability of each grid on the map. The possible values of the arrays are 0, 100, and -1, which correspond to empty, occupied, and unknown grids, respectively. The 1D array is reshaped into a 2D matrix of the map's width multiplied by the map's height. This 2D matrix represents pixels of the map image in black and white, where the coordinate system follows ROS convention. The coordinate system in ROS must be converted to Unity coordinate system. After which, the 2D occupancy map on the Unity environment is displayed by rendering the empty grids in white and occupied grids in black. There are several rendering techniques. In this case, we draw a square of size $map\,resolution^2$ for each grid by creating four vertices shown as the green dots in Fig. 4. Two triangles are drawn in clockwise fashion— (0 – 1 – 2) and (2 – 1 – 3) —to make a quad. The occupancy grid Unity game object is spatially referenced to the common coordinate frame by setting the occupancy grid origin specified by the ROS message to the 2D occupancy grid game object's transform values. In Fig. 5E, the occupancy grid resolution is 10 cm per grid. The map board scale is 5% of the physical world. The occupancy grid map refreshes and re-renders every time Unity receives new message from ROS, revealing wider map coverage as the robots continue mapping.

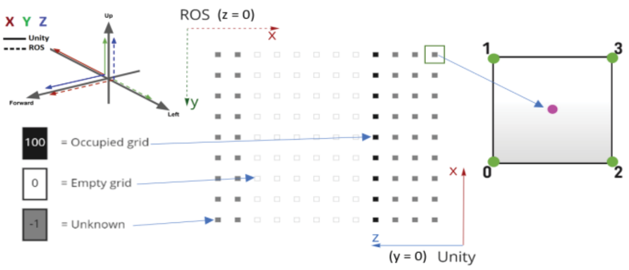


Fig. 4 Occupancy grid rendering in Unity from ROS 2D occupancy grid message.

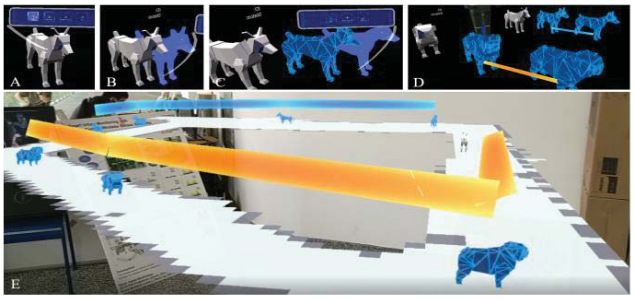


Fig. 5 (A-D) Waypoint interaction user interface. (E) Robot motion planning.

### 3.3 Online Motion Planning and Waypoint Interaction

The HoloLens user can interact with a waypoint cursor by near or far interaction using the MRTK feature (8). In practice, the workflow for robot motion planning proceeds as follows. HoloLens user grabs the waypoint cursor, places it at the desired position and orientation on the mini map, and clicks a button to send the pose of the waypoint cursor to ROS move base goal and simultaneously add it to the list of waypoint queue in Unity environment. If the second waypoint is set when the robot has not reached the current goal, it will queue up in the list of waypoints. When the robot reaches the goal, the current waypoint is removed from the list, and the next waypoint in the queue will be published to ROS. The sequence of the waypoints in the queue are connected by lines—defining the planned path of the robot—and are adjustable for path modification and troubleshooting.

The magenta waypoint cursor in Fig. 1A is an example of a waypoint concept design for a single robot system adopted from (13). We present our waypoint interaction interface which supports a multi-robot system as shown in Fig. 5. The waypoint cursor of each robot is hidden by default to declutter the mini map. Tap and hold on the robot avatar to show the waypoint menu (Fig. 5A). Waypoint cursor of the robot in solid blue will appear when the motion planning mode is confirmed on the menu (Fig. 5B). Place the cursor at the desired position on the mini map and click "add waypoint" to issue the goal to ROS and add it to the waypoint queue as described above. Concurrently, a waypoint marker in meshed blue is marked on the map (Fig. 5C). Fig. 5D and 5E illustrate the waypoint interaction and the online motion planning of the multi-robot system.

## 4. Experimental Validation

The communication of the spatial information was established between ROS and Unity environments via ROS# and ROS Bridge. The Unity game object hierarchy under the map board and the relative coordinate frame of the children's game objects reflected the relative spatial information of the physical world as shown in Fig. 6A. The outline of the occupancy grid in the mini map and the corridor is highlighted in matching colors. Poses of the first and second robots in the digital world represented the real world correctly.

The spatial information of the Ghost Vision 60 robot and the occupancy grid in the mini map was updated in real-time while the robot was executing its mission in the upper left corner in Fig. 6B.

The effect of the mini map can be validated by comparing the relative position of the physical robot and the surrounding obstacle and the relative position in the mini map. A waypoint goal was issued to Ghost Vision 60 as marked by the meshed blue robot avatar (blue star in Fig. 6B). The robot followed the light green path to the goal. In Fig. 6C, the meshed blue waypoint marker disappeared when the robot reached the destination, and the robot avatar coincided with where the waypoint marker used to be.

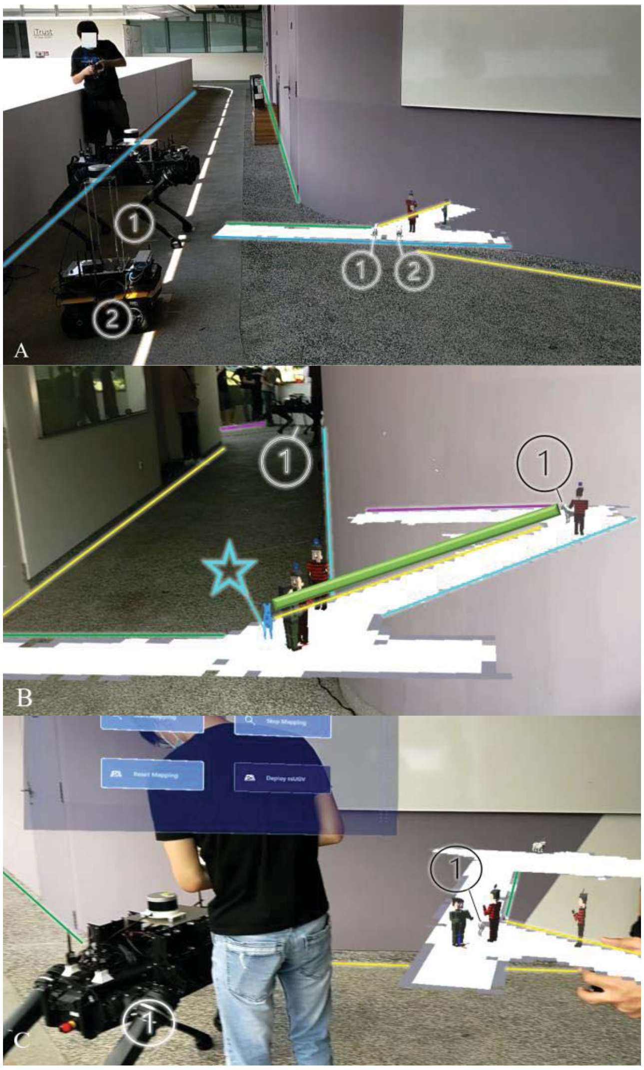


Fig. 6 (A) Verifying the mini map compared to the physical world. (B and C) Validating the online update of the spatial information of the robot avatar and occupancy grid and the accuracy of the waypoint goal.

## 5. Conclusions

Leveraging mixed reality technologies, we introduce the MR platform for online motion planning for mobile robots via HoloLens 2, a novel human-robot interaction system that enables real-time and beyond-proximity communication. The human can visualize the robots' current states and planned paths online and simultaneously troubleshoot or modify the paths through MR interaction on HoloLens 2, which allows human mobility and freedom to observe or execute human tasks in the physical world concurrently.

## ACKNOWLEDGEMENT

This research was supported by Temasek Laboratories @ Singapore University of Technology and Design. We thank our colleagues from Robotics Innovation Laboratory and Singapore University of Technology and Design who provided insight and expertise that greatly assisted the research.

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