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A Transdisciplinary Approach to Holographic Indoor Navigation Using Mixed Reality and Cloud Computing

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Abstract. The advent of Industry 4.0 has led to the need to train highly skilled operators in complex and dynamic environments, through the convergence of physical and digital technologies. In this context, indoor navigation plays a crucial role in the training of Operators 4.0, allowing them to acquire spatial knowledge and specific skills to operate effectively in advanced industrial environments. However, the challenges associated with this technology, such as environmental complexity and obstacles, require an innovative approach to operator training. Mixed Reality (MR) represents a promising technological innovation for the development of these systems. Indeed, MR enables the co-represence of digital and real world, by content overlapping and integrated interaction between virtual and real assets, promoting efficiency, safety and user engagement. Within this scenario, the paper proposes a Holographic Navigation (HoloNav) methodology based on spatial and cloud computing for the development of an indoor navigation application according to a transdisciplinary approach. The application is deployed on the Microsoft HoloLens 2 as MR device, using Microsoft Azure Spatial Anchors (ASA) and Cloud Storage Account resources. This study aims to provide an applied methodology and guidelines for application development, and to analyze the broader social implications and potential for social change of such MR technology to support training processes. The proposed ASA-based HoloNav approach was applied through a case study, where a tour inside the spare parts warehouse was developed for new operators who need to start familiarizing themselves with all the different areas.

Keywords. User experience, Indoor navigation, Microsoft HoloLens 2, Mixed reality, Transdisciplinary engineering

Introduction

The Industry 4.0 paradigm has brought a revolution in modern factories offering a set of key enabling technologies in order to improve the productivity and the flexibility of production systems [1], [2]. Despite this great surge in innovation and the constant

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increasing automation level in manufacturing and logistics, companies still heavily rely on human work to meet the market demand for product mass customization with a reduced time-to-market [3]. Therefore, the companies' need is to increase the workforce skills in a shorten period of time, ehnancing the request for new training methodologies able to speed up the acquisition of knowledge at a high quality level [4], [5], putting operators at the centre of the training processes. This challenge fits perfectly with Industry 5.0 paradigm [6], based on the human-centric design and sustainability, and requires a transdisciplinary approach, that seeks to address complex challenges by integrating diverse knowledge domains [7].

In this scenario, modern technologies such as extended reality (XR, including virtual, augmented, and mixed reality) have the potential to enhance productivity while simultaneously fostering the intrinsic benefits of work [8], including the chance to strive for excellence, foster a sense of belonging within a community, and make meaningful contributions to society (human augmentation) [9]. Moreover, XR technologies have attained a level of technological maturity and hold promise in establishing simulated learning environments, acting as a bridge between theoretical knowledge and practical application [10].

Among the range of possibilities offered by XR, indoor navigation presents a valuable opportunity for training the workforce in industry and logistics, amplifying safety, efficiency, and productivity levels. In fact, safety could be enhanced using mixed reality (MR) suggesting users the safer walking path in production sites and warehouses [11], exploiting content overlapping and integrated interaction between virtual and real assets. Compared to the more consolidated technology of augmented reality (AR), MR allows user to freely interact with virtual elements in a real environment, ehnancing usability and the portability in industrial working context despite higher hardware costs. Moreover, indoor navigation enhances warehouse efficiency by offering 3D maps showcasing key areas and resources, optimizing workflows and resources allocation. Additionally, integrating indoor positioning systems in smart factories enables real-time insights, precise location tracking, and improved productivity [12].

The aim of this paper is to propose a transdisciplinary methodology and guidelines to build a MR application and to evaluate the benefits of its adoption in a real working context, concerning the indoor navigation of a spare parts warehouse in automotive sector. The paper is structured as follows: Section 1 generally describes the concept of indoor navigation and what it looks like in the state of the art. Section 2 shows the proposed methodology based on an ASA-based HoloNav approach, while Section 3 reports its direct implementation in an industrial case study. Subsequently, Section 4 presents a list of guidelines applicable in designing and developing the application. Finally, Section 5 summarizes the study's findings, innovations and limitations.

1. Indoor navigation: state of art

In indoor environments, navigation is facilitated through a combination of tools and visual aids designed to help operators efficiently move through the space and locate items. Signage plays a crucial role, with clear and prominently placed signs providing directions to different sections, aisles, or specific items. Marked pathways are another essential feature in warehouse navigation. They may be delineated using floor markings, such as painted lines or tape, which help define walkways, vehicle lanes, and designated areas for specific activities like loading and unloading. Color-coding is also widely employed in warehouse navigation systems. By assigning specific colors to different zones, product categories, or types of equipment, color-coded systems make it easier for individuals to quickly identify and locate items or areas within the warehouse.

Alongside these traditional navigation tools, technologies such as indoor navigation systems and barcode scanning devices are increasingly being integrated into warehouse navigation strategies. Focusing on indoor navigation systems, this technology provides real-time location information, inventory management capabilities, and route optimization functionalities, further enhancing efficiency and accuracy in warehouse operations [13]. The main field of application for indoor navigation systems encompasses a diverse range of sectors and environments, each benefiting from the improved navigation capabilities within confined spaces. The most significant application of this technology is related to healthcare facilities [14], ensuring patient and staff navigation, while also enhancing visitor experiences within entertainment venues [15], such as museums and theme parks. Moreover, indoor navigation systems have the potential to drastically change urban areas and significantly affect society, much like Google Maps has for outdoor navigation. These systems not only make it easier and more efficient to get around, but they also make it easier for people with disabilities to get around and participate in society. As indoor navigation technology gets better, its impact on society will likely go beyond just helping people find their way around. It will also change how people use indoor spaces and help innovation happen in different fields.

In industrial field, indoor navigation systems seems promising expecially in warehouse context. From the operator's point of view, indoor navigation systems enriches user experiences through interactive and dynamic content and guided routes within buildings, simplifying the process of locating specific destinations for users [16]. Moreover, these systems make operators feel more engaged in the company processes, and this technology helps them feel valued and appreciated by the company, emphasizing the social aspect of the introduction of this technology. From a company perpective, indoor navigation systems could improve operators' safety by providing a tool that gives them alerts in real-time and continuously suggests the safer pathway [17]. At the same time, these systems shorten the training time dedicated to explaining of the warehouse layout, saving resources. Essentially, these systems could act as a bridge between the companies' world and operators' needs, benefiting both from the application of this transdisciplinary approach (Figure 1).

2. Methodology

The proposed methodology aims to provide advanced support to Operator 4.0 during the training phase, focusing on essential skills required for their role in complex work environments such as large warehouses and storage facilities. To achieve this goal, a mixed reality application has been developed and integrated with Microsoft HoloLens 2 hardware to assist the user in navigating indoor spaces. This methodology provides a comprehensive and integrated approach to enhance the operator skills. It offers an innovative and practical training environment by combining mixed reality with advanced scanning and positioning technologies. This optimization of the learning experience is particularly useful in complex and dynamic environments.

The methodology is structured into three key phases:

1. **Application Development**: a graphics engine and specific software package are used to create an application with a custom graphical interface.
2. **Environment Scanning**: the HoloLens 2 device performs a detailed 3D scan of the surrounding environment using a Time-of-Flight sensor (depth camera) as a scanner.
3. **Positioning and Localization of Spatial Anchors**: the placement and definition of reference spatial anchors are strategically done within the surrounding work environment. Their spatial coordinates and respective IDs are saved through a cloud storage system.

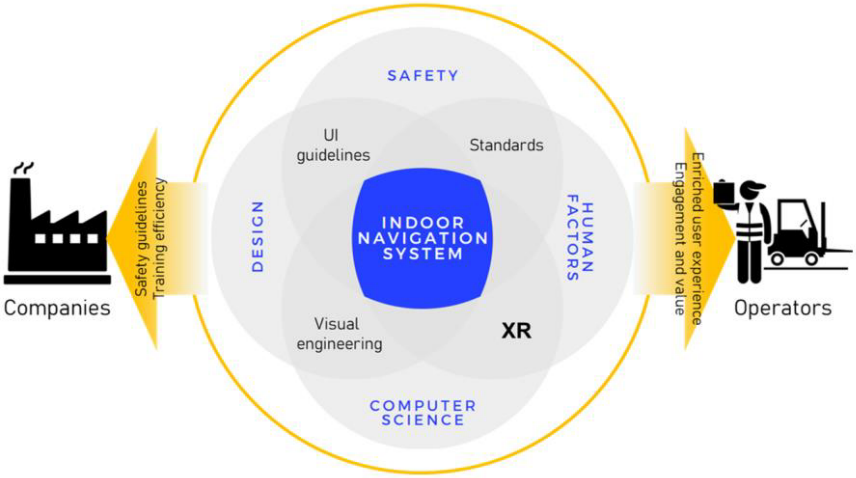

Figure 1. Transdisciplinary approach as a bridge between operators and companies.

After the initial environment scan, the last two phases are continuously performed runtime within the proposed methodology workflow presented in Figure 2. This allows the device to develop a sophisticated indoor navigation system.

2.1. Application development

Initially, a new 3D project is created within the Unity software. Subsequently, the Mixed Reality Feature Tool, a Software Development Kit (SDK) for mixed reality applications, is utilized by importing the Microsoft Mixed Reality Toolkit (MRTK3) package. In the Hierarchy tab, the "Main Camera" is then replaced with the "MRTK XR Rig", a virtual camera provided by the Microsoft toolkit [19]. This "Rig" serves as a foundational structure for developing mixed reality experiences, simplifying the integration of extended reality features across various platforms and devices. Microsoft's MRTK XR Rig acts as a high-level interface for interacting with the hardware device's camera in a mixed reality application, facilitating the creation of engaging experiences. To handle spatial anchors in the mixed reality scene, the creation of a Microsoft Azure profile, a cloud computing platform, is necessary. Spatial anchors identify specific points in 3D space and must be stored in Azure to enable devices to recall them later. In the context of indoor navigation, the objective is to allow multiple users with different devices to share and collaborate within the same physical space. For this purpose, Microsoft's Azure Spatial Anchors service provides a common cloud storage for anchoring positions. ASA, a part of the Azure cloud services, allows for the saving and retrieval of anchor positions based on the anchor ID. This information is accessible by cross-platform devices such as HoloLens 2, iOS devices, and Android devices, facilitating the development of Indoor Navigation applications. Upon completing the mixed reality scene in Unity, the development of the MR application on HoloLens 2 hardware is finalized using the Visual Studio IDE. The technological set-up used is shown in Figure 3.

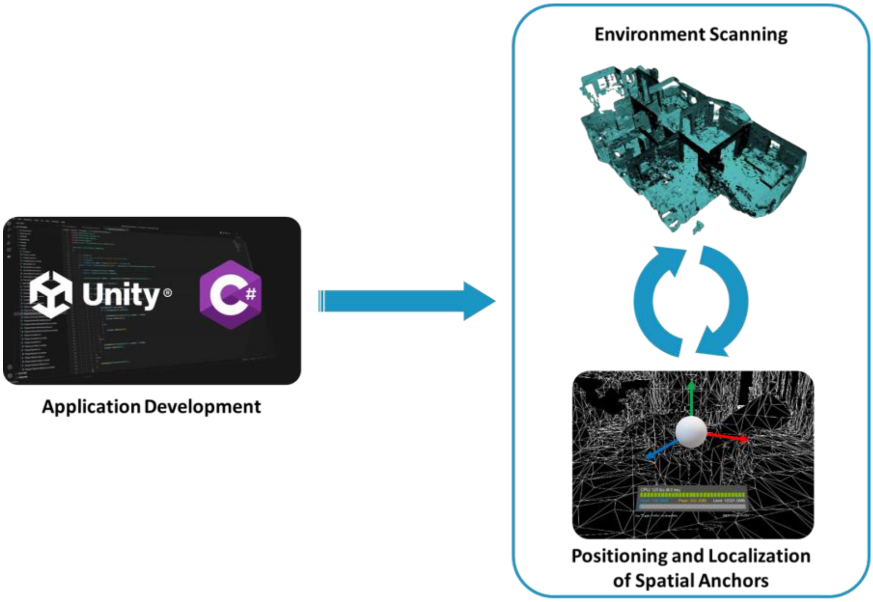

Figure 2. Methodology workflow for an ASA-based HoloNav approach [18].

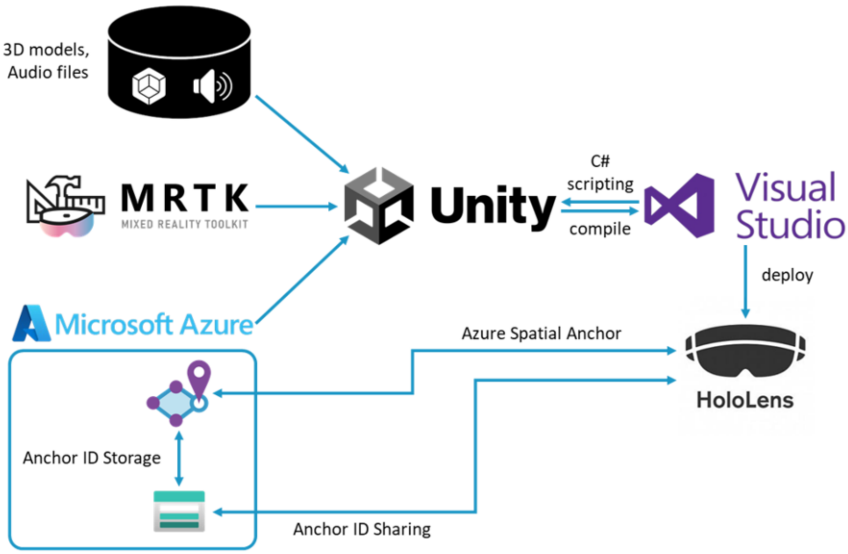

Figure 3. SW and HW technological set-up.

2.2. Environment scanning

Once the development phase of the application is complete, when HoloLens 2 is worn, it initiates a three-dimensional scan of the environment through the use of a depth camera sensor that works on Time-of-Flight (ToF) modeling technology. Integrated into the HoloLens 2 hardware, this technology facilitates the creation of precise three-dimensional models of surroundings. This device allows for the reconstruction of the environment in the form of a point cloud, which is then used to create a detailed 3D model of the environment. During the 3D scanning process, the reconstruction of the surrounding environment can be visualized through the triangle mesh. This spatial mapping process undertaken by HoloLens 2 is essential, as it allows the device to interact with the real world and accurately overlay virtual objects onto its surrounding physical environment. The main strength and advantage of this type of spatial mapping is that it occurs in runtime while the HoloLens is in use, ensuring a continuous update of the 3D map. Additionally, the device saves the map, and area recognition is faster when performed online with the same Wi-Fi network for all scans.

2.3. Positioning and Localization of Spatial Anchors

Finally, the actual launch of the indoor navigation application can be initiated directly from the HoloLens 2. During this usage phase, the device enables the creation and placement of spatial anchors at specific points of interest in the surrounding environment. Each created anchor is then saved in the Azure's cloud storage account, along with any additional information such as photos or brief descriptions, making it accessible from the application at any time. By accessing one's Microsoft Azure profile, users can review their storage, displaying the IDs and the positions of all saved spatial anchors in their respective scenes of reference work environments. When deciding to search for a particular spatial anchor saved in a previous session or project on the device, it guides the user to it, also illustrating the recorded features, such as a descriptive image and text. Furthermore, the display of anchors and the type of visual indication that helps you reach the desired halfway point, such as arrows or paths, can be customized.

This ASA-based HoloNav approach has successfully led to the development of a highly interactive and intuitive indoor navigation system through a mixed reality program supported by the HoloLens 2 device. Its strength lies in flexibility and information sharing among different devices, allowing simultaneous use by multiple operators in the same workplace (Figure 4).

3. Industrial use case

The case study focused on indoor navigation within a spare parts warehouse. The primary objective was to introduce a guided tour to orient and familiarize newly arrived novice operators. Substantial modifications were made to the basic application provided by Microsoft to customize it according to the specific needs of the case at hand. These adaptations included replacing, adding, and repositioning elements in the user interface to optimize usability. A crucial change was made to the virtual anchor model by assigning flags to holograms, as shown in Figure 5. A key element of these modifications is the introduction of a map viewable on the left palm, providing a detailed perspective of the areas within the warehouse floor plan. This interactive and customizable map, presented as both a 2D planimetry image and a 3D map model, allows the user to explore the environment. A distinctive feature of this approach is its interactivity, enabling users to view detailed images, such as photographs, and receive textual and voice descriptions by pressing specific areas. To ensure a personalized and flexible experience, maps can be easily displayed or hidden at the user's discretion through a dedicated button on the left wrist. These targeted implementations help optimize the use of the application in the industrial case study, improving efficiency and visual understanding of key elements of the operational context.

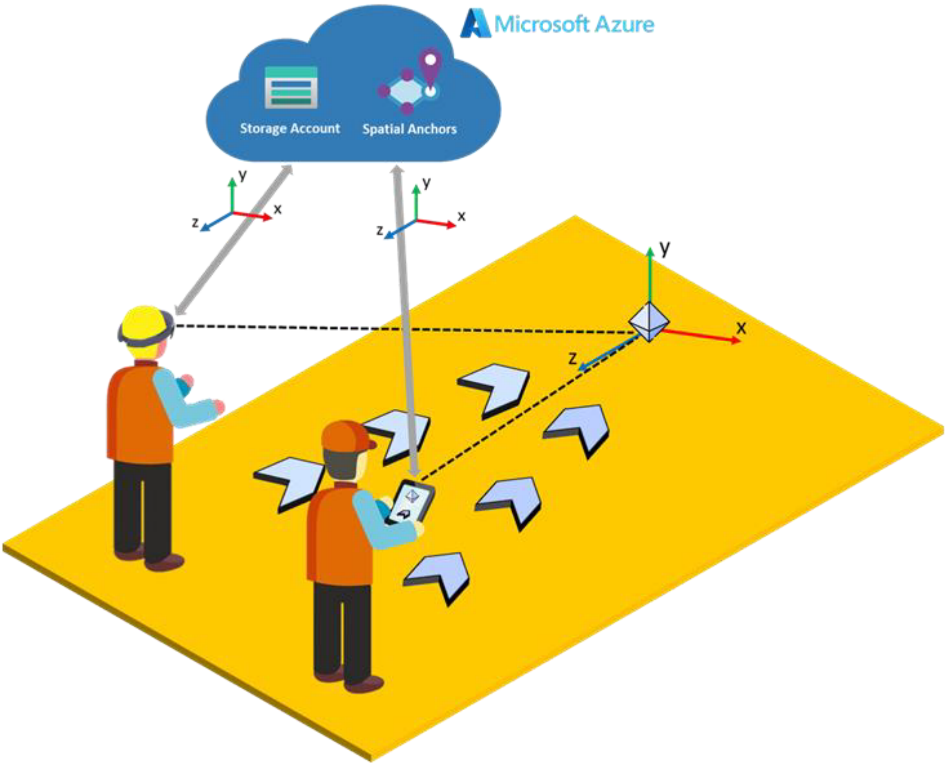

Figure 4. Example of *cross-reality* (XR, Extended Reality) app in indoor navigation.

Special attention has been paid to operator safety, considering that wearing a visor may limit visibility and increase obstruction. In line with safety practices, efforts were made to minimize virtual elements overlaid on reality, carefully selecting and involving operators in the process. Furthermore, directional indicators were positioned to follow specific pedestrian paths within the warehouse, following internal company regulations and thus trying to enhance overall safety within the working environment.

4. Guidelines for MR Indoor Navigation Apps

Based on the experience gained from the case study, we have outlined a set of guidelines for designing and developing indoor navigation apps in mixed reality, with particular regard to industrial environments. These guidelines also serve as a list of best practices for those who like a user-centered approach.

Figure 5. Custom holographic flag used as a spatial anchor.

1. Analyze the requirements and study the environment: it is essential to conduct a detailed analysis of the industrial environments where the application will be used. This involves identifying landmarks, critical areas, and essential information for navigation. This in-depth understanding of the environment will help develop an application that integrates effectively and securely;
2. Follow the safety standards: in addition to complying with safety regulations and avoiding distractions, it is also important to consider the specific requirements of industrial environments. These environments often involve different types of mobile vehicles (pallet trucks, forklifts, etc.), heavy machinery, hazardous materials and potentially dangerous processes. Therefore, your application should be designed to mitigate risks and avoid any form of distraction or disruption to daily operations;
3. Organize virtual elements considering visibility: to enhance the visibility of virtual objects in the industrial environment, it is crucial to implement distinctive colors and visual indicators that can be easily distinguished within the user field of view. Additionally, utilizing virtual lighting techniques can further improve the realism and accuracy of the virtual models by matching real-world lighting conditions. By doing so, workers can quickly identify and interact with virtual objects without any confusion or ambiguity;
4. Design with a user-friendly and intituive user interface: the arrangement of the UI elements in a precise and studied way leads to an easy-to-use interface that simplifies navigation. In addition, the ergonomics (both physical and cognitive) and the practicality of the interface in the industrial context must be considered, without causing too much inconvenience to the operator;
5. Conduct tests and gather feedback from users: both in the preliminary phase and after development, extensive testing is essential to evaluate the effectiveness of the application in conditions similar to those of the industrial environment. Gathering feedback from users in order to make the necessary improvements, in order to obtain information both on the design of the application and, above all, on its actual feasibility and usability in each specific use case.

By following these guidelines, a MR indoor navigation application with HoloLens optimized for industrial work environments can achieve a balance between design and development effort and overall UX. Furthermore, a crucial aspect to consider when following to the guidelines is that the application must not be immersive and should not distort the operator's perception of reality. Rather, it should only serve as a supportive accessory during daily activities without reducing his social engagement. Lastly, before using the technology, it is strongly recommended that the operator undergo a short period of familiarization and training.

The application was tested by warehouse operators that reported a general positive feedback. In general, the use of the application promote a higher engagement level of users compared to the classic training program, based on frontal lessons and planimetry. From the company perspective, this solution represent an opportunity to reduce the training cost and time exploiting modern technologies. Moreover, MR indoor navigation system could increase the operators' productivity receiving real-time indications that adapts dinamically to the operators' point of view and the working environment.

5. Conclusions

The goal of the paper is to encourage companies and decision-makers to adopt new technologies, such as extended reality, for aspects that are currently poorly considered in everyday work, for example training and travel efficiency in large environments (e.g., warehouse, deposits, industrial sheds). As a result, mixed reality-based indoor navigation has immense potential to revolutionize processes, increase productivity, and improve safety standards. Operators can easily navigate complex industrial environments, reducing errors and optimizing workflows. A set of guidelines has been defined to help engineers design and develop the MR application with a transdisciplinary and human-centered approach. Furthermore, an industrial case study was used to validate the methodology and guidelines, with feedback from the company confirming their usefulness. The main limitations encountered are due to the adaptation of the use of the device and the application to the current company safety regulations and the confidence of the operators in its practical use. In conclusion, mixed reality indoor navigation is not only a technological innovation, but also a catalyst for social change. This technology not only improves accessibility and efficiency within indoor environments, but also opens the doors to a series of opportunities to improve the involvement and inclusion of people, including those with disabilities or physical limitations. As further developments, the MR approach could exploit the benefits of cloud computing to exchange information on real-time with multiple devices, allowing the simultaneous use by multiple operators in the same workspace.

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