

# Towards Mobile Immersive Analysis: A Study of Applications

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## ABSTRACT

The latest new technologies of virtual and mixed realities are ready to be commercialized. Their innovative communication channels have created new opportunities and challenges for visualization and visual analytics. At this stage, it is important to understand the state-of-the-art of relevant technologies as well as the impacts to the research fields. This position paper presents the key features of mobile, immersive environments that are different from traditional visualization and visual analytics systems. Through a study of applications in the mixed reality, we present a rich example set of capabilities and applications that address discovery and visual communication in real-world uses. We hope that this work will provide references and promote the research on the topic of immersive visualization and visual analytics.

**Index Terms:** I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques; I.3.8 [Computer Graphics]—Applications

## 1 INTRODUCTION

Over the past few years, newly developed technologies, including big data, cloud, mobile and social networks, have significantly changed our everyday lives. The next big thing is the mixed / virtual reality, as it creates new perception and cognition channels that fundamentally affect how people see and interact with our world [55]. Specifically, **mixed reality (MR)** mixes holograms with the environment around users and allows interaction with holograms and everyday objects together. Represented by innovative devices such as Microsoft HoloLens [56], MR is the ongoing evolution in computing. **Virtual reality (VR)** artificially creates sensory experiences, which may include sight, hearing, touch, and smell. Figure 1 demonstrates several examples of immersive environments from HoloLens, where information and 3D objects are vividly visualized for studying and manipulating in a variety of applications.

This position paper discusses the vision of immersive visualization and visual analytics on mobile devices, which are only becoming commercially available with the latest MR and VR technologies. Specifically, we expect the new immersive environments to be equipped with the three following key features:

- The **mobile** feature of immersive devices allows people to move around freely just like using cellphones or goggles;
- The **immersive environments** provide realistic mixed and virtual worlds surrounding users;
- The **multisensory technologies** allow natural and fluid interactions with virtual objects, such as touch and move them.

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While virtual reality has been studied for years [61, 57], the three key features differentiate mobile and immersive environments from the traditional VR technologies significantly.

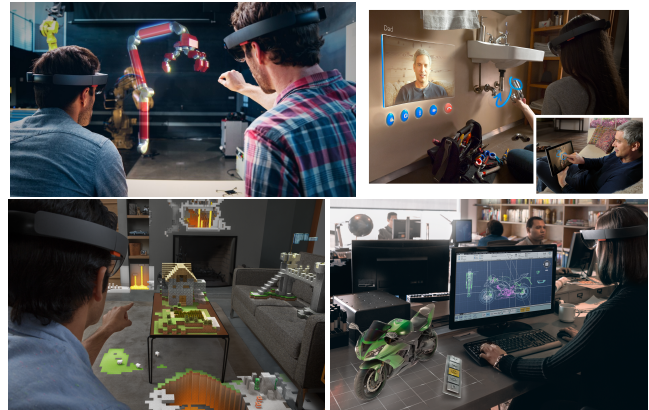


Figure 1: Examples of Microsoft HoloLens [33] illustrate the mobile and immersive environments, providing innovative tools as well as challenges for all related fields including data visualization, interaction, and analysis.

Immersive visualization is still an emerging field. We expect even greater potential of immersive analytics (IA) using the latest advanced MR / VR technologies. We need to explore the ways in which IA differs from and offers benefits beyond traditional visual analytics and virtual reality. To demonstrate these new capabilities and challenges, we use HoloLens for MR as example and studied about 5,000 ideas submitted to the “Share Your Idea” program [26] in the HoloLens community. We summarize five aspects of new capabilities related to IA: new ways to visualize, interact, and analyze data; as well as new ways for decision making and collaboration. We provide examples for each aspect and summarize a comprehensive set of what IA can do to improve human life and advance discovery science.

The remainder of this paper is organized as follows. We first present the latest and upcoming commercial products of MR and VR, which sets the scope of the techniques described in this paper. We then describe the new capabilities and challenges through comparing the visualization systems for desktops and the immersive visualization and visual analytics in Section 2. We also present a survey on the 5,000 HoloLens applications from five aspects related to IA in Section 3, which provide a rich set of applications and references for researchers and developers. At the end, we summarize this position paper in Section 4.

## 2 THE NEW CAPABILITIES AND CHALLENGES FOR IA

### 2.1 The Emerging Technologies for IA Research

2016 is poised to be an important year, with the Oculus Rift, HTC Vive, PlayStation VR, and Microsoft HoloLens all scheduled to launch in the coming months. These devices are becoming commercially available, and the public seem to be increasingly eager to

Table 1: Emerging virtual and mixed environments (\* marks the available and ' marks the products that are commercially available very recently or are announced to be available in the next several months).

Technology Genre	Products	Features
Virtual Reality (VR)	Oculus VR/Rift' HTC Hive' Sony PlayStation VR'	Simulating a physical presence in places in the real world or an imagined world, allowing the user to interact in that world
Augmented reality (AR)	Google Glass*	Real-world augmented by computer-generated sensory input such as sound, video, graphics or GPS data
Mixed reality (MR)	Microsoft HoloLens' Magic Leap	Merging of real and virtual worlds so that physical and digital objects co-exist and interact in real time

adopt them. As shown in Figure 1, such immersive environments have a great potential to become part of our everyday life in the near future. They may dramatically change the ways we see the world, study, work, and communicate. It is expected that most homes will have some form of MR and VR devices just like a modern replacement for TVs by 2030 [62]. As technologies mature and become more available and cheaper to purchase for every home and every office, a study of the immersive environments as the future computing technology is needed.

Table 1 lists the genres of emerging technologies, available and upcoming commercial products, and their features. These technologies often use a head-mounted display device paired with a headset such as a harness or helmet. For example, Microsoft HoloLens supports holographic computing with APIs that enable gaze, gesture, voice, and environmental understanding on an untethered device. A much affordable device, the Oculus VR released last year, has also demonstrated a nice immersive experience.

## 2.2 New Capabilities for IA

Most of the latest VR and MR technologies can be used to support immersive experiences. The following summarizes the key features of mobile, immersive environments.

**Input:** head-mounted display device, multi-sensory input (including eye tracking, voice, and gesture) either embedded with the headset or work separately with controllers.

**Output:** innovative immersive environments with visions and sounds, allowing us to see our world in new ways and transform the way we work with arbitrary objects, information, and people through advanced interaction and collaboration experiences.

**New capabilities provided only by the emerging technologies:** Immersive experiences with *the world as a canvas* - go beyond what a computer screen or a white board can provide, now the entire world can be used for visualization. A more *natural way to interact* - instead of a screen to touch or a mouse to click, now interact with gaze, voice, and gestures. *New ways to teach and learn* - advanced immersive experiences are available for engaging students and fostering learning, in both traditional classrooms and online courses. *New ways to collaborate and explore* - people at the same or different locations can work together, share different perspectives and opinions, and are aware of each other's status.

Table 2 overviews how we compare traditional systems with immersive environments from the perspective of input, output, location, and relationship between data and user. We expect that new perception and interaction channels provided through new devices will create new interaction mechanisms and new performance metrics (beyond just frame rates) for various visualization applications.

## 2.3 Justification and Challenges

Our vision is supported by the fact that virtual worlds have been studied for a number of purposes [66, 59]. Our vision is also supported by the following relevant theories of perception, cognition, and existing research and theory on virtual reality.

**Perception.** We humans use our senses to perceive information in the form of different stimuli, which we interpret and understand through cognitive processes. The immersive environments will provide advanced visual stimuli and have a great potential to enhance our experiences.

**Interaction.** People are used to learn the computer operations, but now a five-year-old child without any previous computer experience can play with an iPad spontaneously. This is because we use our senses of vision, hearing, and touch for interacting with the world every day, we are heavily accustomed to processing information this way. Novel multisensory interaction technologies will let us interact with data in ways that are natural to us and therefore easy to understand.

**Challenges:** The technologies will fundamentally transform the ways people communicate, create, collaborate, and explore. Specific problems include new perception and cognition dimensions, new interaction methods, new visual effects with both static and animation, and new collaboration solutions. Despite all the new capabilities of immersive environments, we also need to be aware that these environments will increase the perception, cognition, and sensory loads of users [60]. Studies have shown mixed results for using VR, such as VR games for education [65] and it is not necessary to utilize all the senses [58]. Qualitative and quantitative studies are crucial to assess the effectiveness of virtual worlds [64, 63].

## 3 STUDY OF IA APPLICATIONS

To explore the needs of immersive visualization and analytics, this study summarizes around 5,000 submissions to the "Share Your Idea" program [26] in the HoloLens community from several aspects of IA. While not all the ideas can be applied to IA directly, many of them can be transformed or adopted by IA. The benefits this study are multifold:

- Providing a collection of what can be done for immersive visualization and visual analysis.
- Suggesting key features that IA can provide and the features that are different from desktop visualization and analysis.
- Demonstrating a large collection of applications.

From the diverse applications in the study, we expect that the field of IA will cover several topics related to visualization, analysis, and decision making. We summarize the ideas according the following five categories: new ways to visualize, interact, analyze data, decision making, and collaboration. Representative applications are selected based on the popularity in the program. Among which, the three core components of visualization and visual analytics - visualization, interaction, and visual analysis - are expected to be revolutionized with the latest VR and MR technologies. The new technologies will also affect how people work, such as decision making and collaboration.

Table 2: Comparison between conventional and immersive environments.

	Traditional Desktop Visualization	Immersive Visualization
Input	Mouse and keyboard	Multi-sensory (gaze, sound, touch, movement & gesture)
Output	Monitors or screens with limited size and resolution	Any 3D locations in the mixed world that is unlimited virtually
Location	Office or lab	Any locations (with Internet for accessing data server)
Data & User	Separated by screen	Users surrounded by data with immersive experiences

### 3.1 New Ways of Visualization

The new technologies will bring opportunities to create new ways of visualization. According to the design of visualization, we categorize all submissions into the following four types: flexible transition of visualization from desktop to virtual / mixed worlds with the flexibility of placing displays on any location; mixed reality visualization for overlaying data with the real environments; new 3D visualization experiences with integration of data and world; and immersive visualization that places users and data jointly in the same world.

Figure 2 demonstrates examples of new visualization types. Except the second type that is only available in MR, all the other three types can be delivered by both MR and VR. In the following, we provide examples to describe each type of visualization.

#### 3.1.1 Flexible Transition

Flexible transition visualizations can place the conventional desktop visualization and visual analytics systems in the immersive environments at any physical and virtual locations in a flexible setting. For example, several applications propose the idea of desktop everywhere. A virtual desktop with one or multiple displays is setup for users to work as if on a conventional desktop. Another option is to utilize large spaces in the real or virtual environments and visualize data in the conventional way. For example, the “Virtual Periodic Table (VPT)” [48] proposes to visualize the periodic table and demonstrates how the elements work. The “HoloOffice” builds a virtual office with similar settings as a conventional office supporting users to work everywhere [18].

#### 3.1.2 Mixed Reality Visualization

The MR visualization overlays data with objects in the real world to create strong correlations of data and the surroundings, allowing people to interact with virtual objects as if they are real. For example, the idea of “Future of medicine! MRIs displayed in 3D through HoloLens” [11] proposes to display the MRI in the correct location of the body, which allows physicians to better view the injuries and produce simulations of different treatments procedures. The “Heat Overlay” project mixes the information of warmth loss of houses through heat sensing technology with the real environments [13]. This technology may become a key driver in professional use. A similar idea for another different application is “Home Interior Design” [30], which allows users to describe the furnitures they want and obtain a mixed reality preview in realtime.

#### 3.1.3 Integration of Data and World

There are a large number of applications that integrate data with the real-environments nicely. Such visualization will provide new 3D experiences through visualizing data in a 3D subspace of the world and allowing intensive interaction with the virtual data. For example, the “HoloFire Firefighting Simulator App” proposes to utilize HoloLens to simulate fire behavior [23]. HoloFire may also simulate various building burning scenarios as holographs that can be cooperated on by different fire station teams through interaction and collaboration tools. The “HoloLens Ocean Discovery App: Past, Present & Future” provides a unique educational experience that would make the deepest ocean accessible to everyone in the

mixed environment [28]. A three-dimensional holographic cut-away model of an area of ocean stretching from surface to seafloor can be created, and it will allow people to visualize the ocean in unprecedented detail. The “Protein Database viewer” [41] is proposed to improve biological science research and education. The mixed reality displays information from the protein database (PDB) to enable users to understand structures of biological molecules, which is difficult due to their vast yet subtle complexity.

#### 3.1.4 Immersive Visualization

Immersive visualization provides an immersive 3D experience to the extreme. For example, the “Holo Space” [20] places the user at the position of the Sun and visualize all the information that fills up the whole room. The user can manipulate individual object and travel through the room watching different components. The “YouLoox Holographic Operating System (Environment)” builds a fully customized 3D operating system [53]. Several example snapshots from science fiction and fantasy movies, such as “The Avengers” and “The Matrix”, are used to demonstrate the effects of immersive visualization.

### 3.2 New Ways of Interaction

New input channels will create new designs of interfaces that are not limited by devices and spaces. Also, we expect researchers and developers will explore new, natural interaction mechanisms that are beyond traditional mouse and keyboard.

#### 3.2.1 New Ways to Live with Data

The new MR/VR technologies may significantly change the way we live with data. For example, mixed reality experiences can be used for shopping in the virtual environments without the needs of traveling to stores [34], cooking by analyzing the products in the fridge and suggesting recipes [47], teaching pianos by highlighting the keys to press in order [36], designing home gardens [21], and monitoring and giving wellness / fitness instructions [29].

We expect that new ways of visualization will promote new ways of interaction. The “Animated Storybook” proposes a new way of reading books [5]. The pages can unfold revealing a scene on top of the pages like a popup book and play animations. Users can walk around the book to see the scene from different directions. We may even have a “virtual pet” of any species that we can easily interact and play with [37].

A number of ideas have been developed for driving, such as “HUD for Driving” which overlays information such as current speed and directions on roads while driving [31]. Similar ideas have been proposed for pilot [39], browsing holographic maps [42], geo-coaching assistant for adventurers [12], night vision assistant [38], indoor navigation [27], and walking tour [52].

#### 3.2.2 New Interfaces

The immersive environments will be used to design new interfaces for various data applications. For example, the “Holographic Web Browser” build new browsers which can search multiple web pages from multiple resources at the same time and highlight the most recent information [25]. The interfaces requiring special devices previously may become available for everyone at home, such as the



Figure 2: Examples of new ways of visualization for flexible transition, mixed reality visualization, and integration of data and world. A variety of additional examples can be found in the program, such as HoloOffice for flexible transition [18], MRI hologram for MR visualization [11], fire simulator for integration of data and world [23], and Holo Space for immersive visualization [20].



Figure 3: New ways of interaction - using HoloLens to explore a Minecraft world. Additional examples include animated storybook [5] and HUD for Driving [31].



Figure 4: Example of new interface in the immersive environments [33]. Additional examples can be found in applications such as flexible touch spaces [22], smart cities [19], and an interactive 3D GUI [32].

“virtual recording console” that can project all console components onto a flat surface to replace a very expensive and elaborate piece of gear - recording console [49]. It is expected that the interfaces like “HoloDynamics CRM Lens” [22] will become popular.

The interfaces for 3D GUI will be brought into the new millennium with natural 3D interactions. As shown in Figure 4, the “Interactive 3D GUI” uses a movie snapshot to show that a graphic interface can do anything with your PC from playing music, browsing the internet, to playing games [32]. Applications such as “3D editing” [2] and “3D Drawing” [1] provide interaction functions for creating and customizing prototypes in 3D. The advantages and disadvantages of 3D visualization may need to be discussed in the immersive environments due to the natural 3D interactions brought from the real world.

### 3.2.3 New Interaction Mechanisms

With the new immersive environments and interaction channels, new interaction mechanisms will be designed and developed. For example, the “Breaking the barrier of communication” idea enables deaf-mute people to communicate through HoloLens, where gestures and voices are automatically translated [6]. The “Help Your Young Surgeons” proposes to revolutionize surgical trainings with mixed or flexible visualization using HoloLens [14]. It is suggested that young surgeons of all specialties can learn the remarkably unforgiving intricacies of complex surgical anatomy faster than ever before. The “Molecule Builder” allows users to visualize molecular structures in their given configuration, rotated, flipped and moved with hand gestures within the field of view [35].

With the popularity of MR and VR technologies, the availability of data resources and requirements of travel will be also reduced significantly. For example, the “Anatomy.Aug” places specimens

on bookshelves and allow students to examine different bodily systems such as nervous, circulatory and lymphatic easily [4]. Similar applications have been shown in the previous visualization and interaction sections.

## 3.3 New Ways of Visual Analytics

The new ways of visualization and interaction will promote new visual analytics methods that provide advanced functions for analyzing data and information.

### 3.3.1 Immersive Environments for Analyzing Correlations

Many visual analytics approaches can be transferred to the immersive environments and expanded with the new interaction techniques. For example, the “Visual Explorer for Excel Data” creates 3D charts one can throw on the floor or table in a meeting to explain and investigate data typically hard to convey [50].

Immersive environments will provide large rendering spaces allowing simultaneous visualization of information from multiple resources. Heterogeneous information can be visualized side-by-side in the 3D immersive environments in a number of applications, such as floating virtual panels [10] where multiple persons can use their phones to manipulate the scene in real time. The application of “Player stat tracking overlay” allows visual analytics functions by overlaying statistics of the game or players on the field [40]. The “Surround Search Engine” will allow users to visualize data around and explore complex relationships [44].

### 3.3.2 Visual Analytics with Advanced Interaction Support

We expect that more advanced, natural interaction mechanisms will promote new visual analytics methods. For example, the “act as a calculator by sight” will allow users to see the middle results easily while trying to solve a problem [3]. Similarly, “Holo Documents: Overlay data on top of document” proposes to build holo documents that overlay relevant information on existing document layers based on user rights [16]. The “visualization of runtime code” application visualizes the running code so that programmers can see how the program behaves at run time and gain insight on the situations of the runtime code [51]. The application of “Holographic visualization of large interactive data collections” proposes to visualize and interact with very large data collections [24]. You can group, sort, filter, zoom and interact with all kinds of collections: photos, videos, messages, calendar items, shopping lists, tweets, files, and virtually anything.

### 3.4 New Ways of Decision Making

Many applications are proposed for decision making in a number of fields, ranging from daily operations at a factory, medical center, and smart cities to emergency response during disasters. For example, The “factory of the future” suggests that human is the core in the factory of the future and mixed reality can be used to support regular maintenance procedures [9]. For example, users can move within a warehouse and see the contents of any container without opening it. Similarly, remote support can visualize the scenarios and provide suggestions without traveling. The “Holo - Profile” is used to evaluate job candidates through Holo-profiles containing the candidates’ 360 full body profile and their basic information, skills, interests, work experience, language, matching percentage based on the requirements defined [15]. The “HoLo Medical (Health) Diagnostic Center” allows doctors to create a holographic copy of human being and analyze the medical condition of a patient quickly [17]. In addition, a copy of hologram can be saved and compared with previous records to assist diagnosis.

In fact, such ideas can be extended to many regular and critical operations in real-life. The application of “Holo Smart Cities” mixes information with the real world to enhance security and to prevent terrorism, crime, robbery and disaster [19]. A similar idea is used in “TSA Screening Augmentation” [45]. The application of “Disaster management by telepresence” proposes to use HoloLens for decision making [7]. Specifically, when a disaster happens, people can use HoloLens to connect to a disaster intervention professional for guidance of appropriate actions.

### 3.5 New Ways of Collaboration

The new methods from the four topics above, visualization, interaction, visual analytics, and decision making, will promote new ways of collaboration. A number of ideas are devoted for virtual meetings, allowing people to attend a meeting from anywhere in the world at anytime, as shown in Figure 5. For example, with HoloLens you could be sitting in your living room while in the middle of your class or meeting with all of your fellow peers/colleges [46]. The “See Who You Work With” application facilitates collaboration by allowing managers and individual contributors to identify who they are talking to, and get an instant snapshot of that person’s group, high level skill set and current projects [43]. The “Yu-Gi-Oh with HoloLens” is designed for a board game called Yu-Gi-Oh from Konami [54]. The goal is to enable all players to share the vision and see all displayed object on the field. The “Enjoy Memories with Hololens” proposes to capture users’ favorite memories in the form of still images or videos and share these special memories in 3D mixed environments [8].

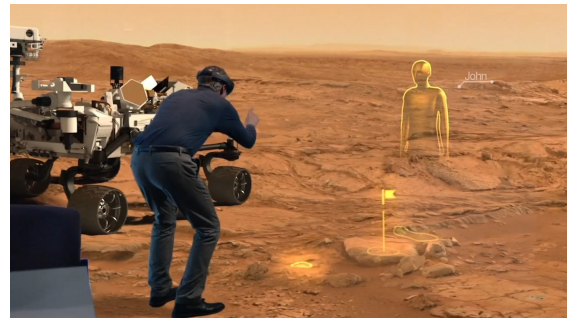


Figure 5: New ways of collaboration. Additional examples can be found for collaborative analysis [54] and virtual meeting [46, 43].

## 4 CONCLUSION

We believe now is the right time to explore immersive visualization and visual analytics. In this paper, we show the latest technologies available and anticipate new capabilities and challenges. We also describe example applications and key features of IA that are different from desktop visualization and analysis. These examples are proposed from the view points of users and they provide a nice collection of potential capabilities of immersive analytics, which may stimulate innovations from researchers and developers. By making a focused research investment in perception and interaction in relation to computing power and devices, we expect that many ideas described here will become a reality in the near future.

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