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Master’s Dissertation 2022

A System for Improving Shopping Atmospheric Experience in Brick-and-mortar Supermarket Using Augmented Reality

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SUMMARY OF MASTER'S DISSERTATION

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Title

A System for Improving Shopping Atmospheric Experience in Brick-and-mortar Supermarket Using Augmented Reality

Abstract

Recently, brick-and-mortar supermarket and convenient store are facing fierce competition threat from online shopping, especially customers leaving and shifted to online shopping. Shopping habits are changing but brick-and-mortar stores are still important in daily life. Shopping atmosphere as an important factor in shopping process, dramatically impact on hedonic shopping intention. In order to attract customers back to brick-and-mortar supermarkets and convenient store, In the thesis, I designed a prototype virtual atmosphere system in brick-and-mortar convenient store, to provide interesting and exited shopping experiences in daily life with the use of HoloLens 2—an AR glasses. By adopting Mehrabian and Russel atmospheric model, I also verified the multiple virtual atmospheres can impact customer's emotional feeling, including pleasure and arousal level. Emotional feeling, especially pleasure feeling was awakened, then influence user's shopping intention (in-store explore intention and patronage intention). But limitations exist, due to its application in brick-and-mortar supermarket and convenient store, business model should be also be explored in the future.

Keywords (5 words)

Augmented Reality, Shopping experience, Virtual atmosphere, Shopping intention, Brick and mortar convenient store.

Contest

1. Introduction

1.1. Brick-and-mortar versus Online

Brick and mortar refer to a physical presence of an organization or business in a building or other structure. Customer browses the available goods or services presented by one or more retailers with the potential intent to purchase a suitable selection of them. Brick-and-mortar supermarkets have long-lasting servicing for customers. Along with informational revolution, online shopping is catching up and overtaking traditional methods of purchasing because of the quick growth of Internet services. According to estimates from the Japanese National Supermarket Association in Figure 1.1, sales income for online supermarkets will increase from 6.7 trillion yen in 2014 to 12.2 trillion yen in 2020. However, the sales revenue of traditional supermarkets has barely increased. In Figure 1.2 The number of average weekday consumers per day has dropped from 2004.5 in 2014 to 1835.2 in 2020.

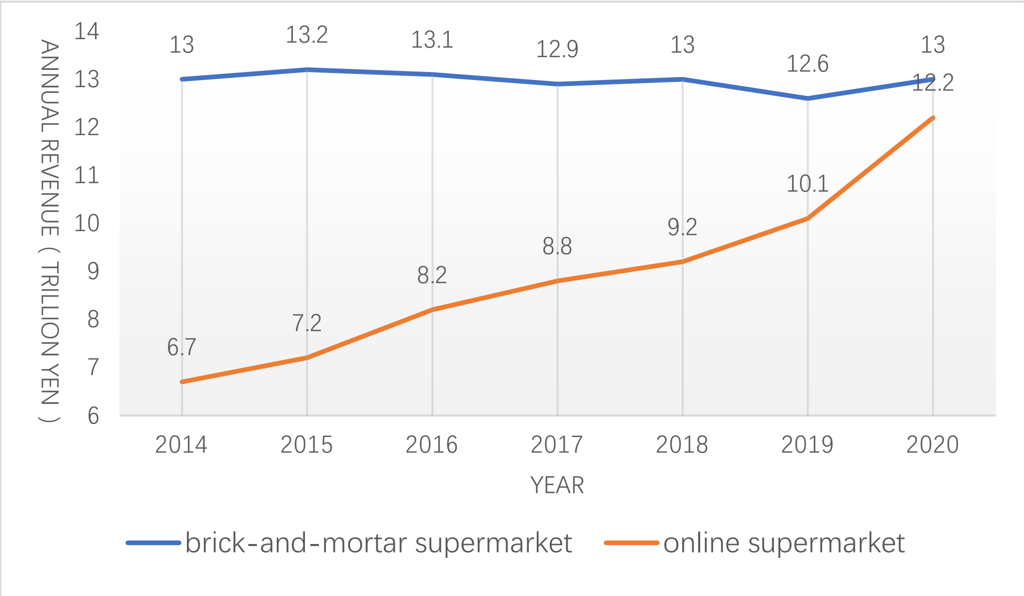

Figure 1.1 Annual Revenue comparation

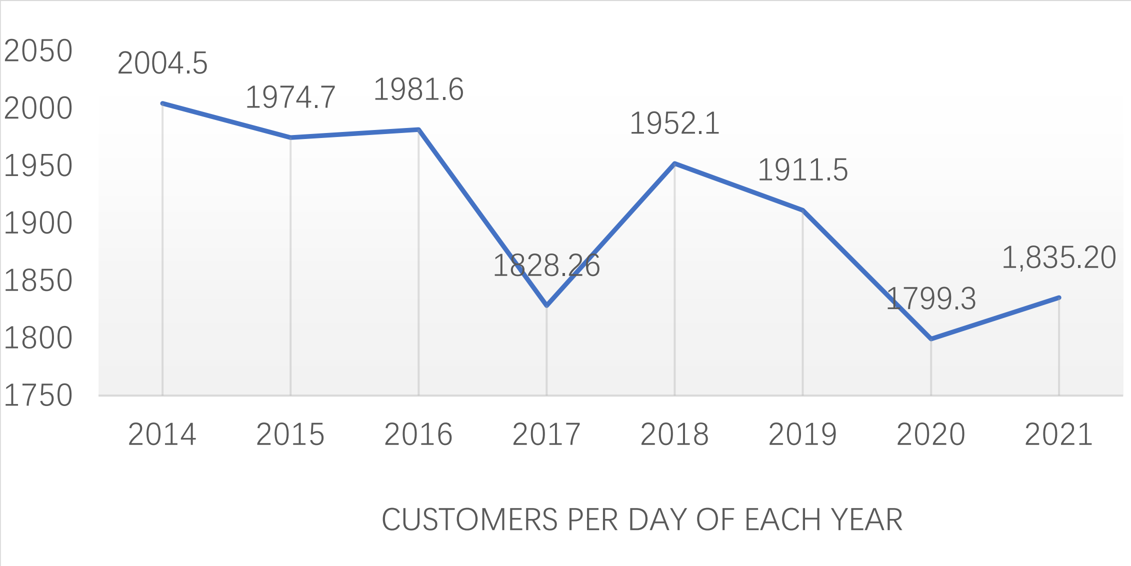

Figure 1.2 Customer Per Day of Each Year

Nevertheless, the situation is not only happened in Japan but also worldwide, ecommerce sales make up a growing share of retail. As recently as 2017, online sales accounted for just 1/10th of all worldwide sales[1]. According to CNN's report, in May 2022, online retail sales increased 2.2% compared with the same month a year prior, according to payment data released by Mastercard Tuesday. In-store sales grew at a much faster clip of 13.4%[2]. Data from Office for national statistics in UK in Figure 1.3 also shows a high growth of Internet sale ratio from 11.3% in 2014 to 30.7% in 2021. It is evident that online shopping poses serious threats to traditional supermarket and convenience store. Online shopping took a large number of customers from brick-and-mortar store, a shopping behavior shift is happening, and the tendency might be strength in the future.

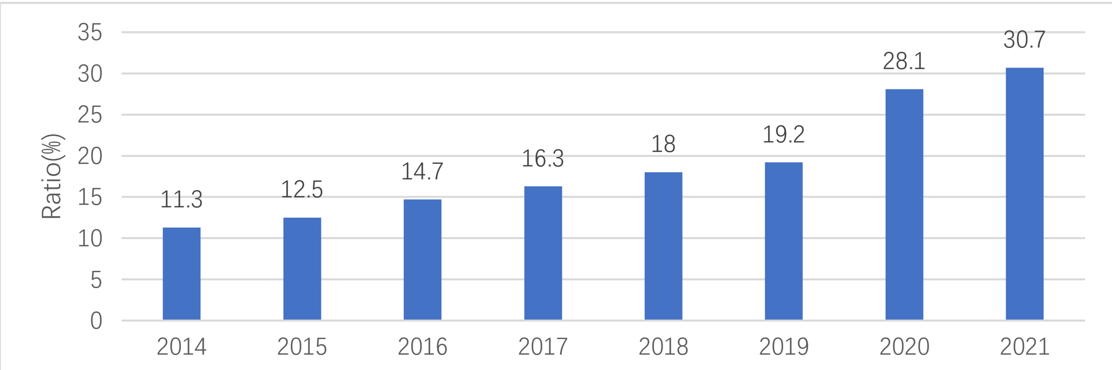

Figure 1.3Internet sales as a percentage of total retail sales by year (ratio) (%)

The Internet substantially reduces search costs, grants easy access to product and price information and facilitates product comparison. Online shopping involves no travel, product carrying or restrictions on shopping hours, offering greater accessibility, convenience and time saving. But online shopping does not permit physical examination of the products (feel, touch, sample and trial), interpersonal communication or instant gratification, and often incurs shipping and handling costs. In contrast, offline shopping allows physical examination of the products, interpersonal communication and instant gratification, but involves high travel costs and search costs, and often has restrictions on shopping hours, especially in countries with strong labor laws[3]. Because of perspective characteristics of online and offline, some users would choose to check out product offline and purchase products online. In the situation, how to attract customers to shop in brick-and-mortar store is need to be research.

1.2. Supermarket and convenient store overview

Supermarket is a self-service shop offering a wide variety of food, beverages and household products, organized into sections. The traditional supermarket occupies a large amount of floor space, usually on a single level. It is usually situated near a residential area in order to be convenient to consumers. The basic appeal is the availability of a broad selection of goods under a single roof, at relatively low prices[4]. In Japan, AEON, 7&i holding, Life cooperation, valor holdings, United supermarket Holdings are five top revenues companies in supermarket industry. Worldwide, growth continues apace. The number of Wal-Mart outlets alone increased by 50% between 2001 and 2005 from 4,189 to 6,287. In the past decades, supermarkets have developed into a mature industry.

Convenience store is a small retail business that stocks a range of everyday items such as coffee, groceries, snack foods, confectionery, soft drinks, ice creams, tobacco products, lottery tickets, over-the-counter drugs, toiletries, newspapers and magazines. Convenience stores usually charge significantly higher prices than conventional grocery stores or supermarkets, as they buy smaller quantities of inventory at higher per-unit prices from wholesalers. Customers benefit from their longer open hours, more convenient and greater number of locations and shorter cashier lines[5].

For supermarkets and convenient stores in different location, diverse kinds of competition modes exist. One the one hand, supermarkets in rural areas provide service for residents within a certain distance, provide wholesales shopping for customers. Consumers in rural areas have limit supermarkets choices, thus led to nonserious competition for supermarkets. On the other hand, supermarkets in city area have relatively fierce competition in a certain distance of area. Supermarkets have to positioning at certain customers, and provide certain kinds of products or services. With the chase from online supermarket service, consumers have even wider range of shopping choices, which furthermore results in more fierce supermarket competition. Under this circumstance, brick-and-mortar supermarkets are now finding more ways to maintain and attract more consumers.

1.3. Advancement on shopping experience

The role of emotions, fun, and pleasure in consumer behavior is now widely recognized as being of key importance, and consumers' shopping is usually discussed in terms of its “goal-oriented” or “utilitarian” value and its “recreational” or “hedonic” value[6]. When shopping in supermarket or convenient store, customers always tend to be “goal-oriented”, purchasing daily necessaries, and sometime walking around for others products or services which is not necessary but interested in. Supermarket also act as a daily visit place, customers spend times inside might feel excited when they find discount, interesting products, or talking to sales. Except for these factors, the atmosphere inside store also impacts customers emotional feelings, cognition and behavior reaction, forming an overall sense toward products faintly.

Because customers differ in their preferences and purchasing habit, and their mobility is enhanced by increasing availability of information, firms invest in technologies that help them gain detailed understanding of their customers, allowing them to know how to respond to customer needs and market products and services more effectively[7]. Targeting at different group of consumers and satisfied their needs, different designed and researches are ongoing. Omega Mart, an immersive art experience created by Santa Fe-based arts and entertainment company Meow Wolf, provided a one-of-a-kind installation that turns an unassuming supermarket into a psychedelic and strange experience. Nations by Ocean Fresh Group opened a huge supermarket combining grocery, park, quick-service restaurant and amusement park[8]. The strategy of these operations has attracted a lot of customers by providing abundant products, services, as well as creating values for different target customers.

Given these competitive developments, the selection of an appropriate operating strategy of maintaining customers may be said to be of increasing importance to the success of firms. In recent years, supermarket and convenient store rapidly adopt a wide range of new technology to provide more interesting, attractive, quick, considerate, complete service to maintain customers[9]. To better create an attractive atmosphere for nowadays, nowadays advanced interactive in-store technologies provide brick-and-mortar retailers with a wide range of opportunities to interact with customers. These new and futuristic technologies can change the customer experience by making the shopping experience more convenient, changing how the customer shops, and/or changing their interactions. Continual innovation and digitalization are critical when helping retailers to create a sustainable competitive advantage. For example, amazon use a combination of computer vision, deep learning, and sensor fusion technology to automate the payment and checkout process. This means that customers can enter the store, pick-up items, and leave without queuing or checking out, while payment is automatically made through the Amazon Go app. H&M has installed voice interactive mirrors in their New York City flagship store. Those mirrors "wake up" when someone looks at it long enough and offers selfies, style advice, and discounts. Evidences all show the application of new technology has become more common into brick-and-mortar shopping, providing more access to enhance shopping experience.

1.4. AR, VR and MR

In this section, I am first to introduce the definition of Augmented Reality (AR), Virtual Reality (VR) and (Mixed Reality). The early 2000s saw the increasing adoption of advanced technologies by retailers in both their physical and online stores, to enhance both the store environment (i.e. the place where the product is bought or consumed), and the shopping experience. This is especially true for what can be termed 'consumer-facing' technology; namely technologies and devices that the consumer experiences directly whilst in the physical or online store, such as interactive screens, online product visualization and customization, digital signage, etc. Amongst these technologies, augmented reality (AR) and virtual reality (VR) applications are rapidly evolving and increasingly increasingly used in retail environments.

1.4.1. Virtual Reality

Virtual reality (VR) is not confined to entertainment boundaries. While people associate the term 'virtual' with advanced video games that offer an enjoyable and indulging real-time experience, VR increasingly plays a prominent role in the contemporary business landscape [10][11]. Virtual reality is a multi-sensory experience defined as real-time inducing graphics with multi-dimensional framework, complemented by a display technology that provides the end user with model integration[12]. It leaps to the forefront of technological advancements and creativity across various industries including construction, aerospace, and oil and gas among other fields with the aim to improve the lives of people[13][14]. Interestingly, VR can pave the way for robust transformation in the world of retail whilst facilitating the logistics, business management and customer experience[15][16]. Virtual reality is undoubtingly altering the way shoppers, brands and retailers behave nowadays[17] (Grewal et al.,2017).

The prominence of VR in the world of retail and its impact on the demise of physical stores can no longer be overlooked nor placed at the back end of priorities. In an era of fierce competition, VR continues to expand in the business world affecting retailers and consumers alike[17]. Accordingly, the thrust of VR has lately attracted not only the interest of many researchers, but also that of retailers[18]. In order to avoid being carved out of the market because of a limited customer experience, numerous retailers find themselves enticed to strategically rearrange the way they conduct their business[19]. In fact, the customer experience provided by innovative retailers is being altered through the likes of virtual reality applications, which are enabling shoppers to interact with different touch points in innovative ways[20]. Retailers are nowadays facing increasingly more demanding customers who expect satisfying experiences alongside the products and services that they seek[21]. Undeniably, consumers value the experience of enjoyable and memorable moments provided by companies that strive to engage with them in a customized and personalized manner[22]. Besides, the human brain is believed to enhance the virtual experience provided by some retailers and brands through the activation of some personal past experiences[23].

Meta have Oculus Quest 2 and Oculus lift as main products, they all contain two ergonomic consoles as main controller, 9 axis gyro sensors empower precise special operation. Oculus Quest 2 in Figure 1.4have independent core processor inside to run applications, while Oculus Lift need to connect to PC for external processing. Oculus Quest 2 have embedded sensors in HMD to detect surrounding environments and movements. Oculus Lift need external dual sensor to detect user motion, which limits user’s move space. Hand tracking function are now provided in Oculus Quest 2 as a beta trial using 4 RGB cameras and advanced algorithm capability.

Figure 1.4 Oculus Quest 2

1.4.2. Augmented Reality

Augmented Reality (AR) was defined as a real-time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it[24]. AR is both interactive and registered in 3D as well as combines real and virtual objects. Augmented Reality aims at simplifying the user's life by bringing virtual information not only to his immediate surroundings, but also to any indirect view of the real-world environment[25]. AR technology are considered not to restricted in specific type of display devices, augmented vision for sure, augmented audio, augmented smell, augmented touch, augmented temperature and so are also parts of the field.

However, it should be realized that any form of sensory information (e.g., vision, sound, touch, smell, and movement) can be augmented in a digital way [26]. It should also be noted that the perceived VR can be augmented by similarly superimposing other content onto it. The term "augmented virtuality (AV)" has been used to describe the augmentation of VR [27]. Generally speaking, AR technology has garnered large attention in the past decade and has been investigated in contexts such as education[28], in the workplace [29], phobia treatment [30], as well as in countless leisure applications, perhaps most considerably in games [31][32][33]. In shopping-related contexts, AR has been investigated in online web shopping settings, in-store and mobile shopping apps [34][35].

AR techniques in retail field are not fresh, for example, Ikea use AR apps on smartphone to help users fit furniture in consumers' room. Nike use AR apps SNKRs on smartphone to help customers pre-try shoes and confirm size. Makeup brand use AR mirror in offline store to help consumers try lipsticks. With the more developed sensor technology, except for the most widely used RGB camera, depth sensors, focus sensors, thermal sensors are also widely used in some AR devices. Traditionally, QR code is widely use as locate mark for virtual objects or content. 2D QR codes are squared and pixelated and can be scanned from your phone's device to trigger a specific type of content. QR codes usually deliver a website, text, image, or similar information.

Now, object-based mark capability and space-based location capability are available with the help of

SDK tools. Object-based mark capability consist of Object scan &modeling and object detection. Object scan &modeling can be done with professional scanning device, RGB cameras or depth camera. Professional scanning device, like body scanning technology, is an application of various technologies such as Structured-light 3D scanner, 3D depth sensing, stereoscopic vision and others for ergonomic and anthropometric investigation of the human form as a point-cloud. The technology and practice within research have found 3D body scanning measurement extraction methodologies to be comparable to traditional anthropometric measurement techniques. Object Detection Augmented Reality is majorly created and developed on Vuforia, which is capable of recognizing 3D Objects. It ensures seamless recognition of flat, convex and volumetric objects. Using object detection and recognition enable user confirm pears data based on real pear, or providing valuable information.
Space-based location capability ensure the capability of detecting specific space and generate according contents. Space-based location capability consist of Space scan &modeling and space detection. Vuforia provide tool for iOS device with LiDAR sensor to scan a certain size of space. The Area Target Generator (ATG) is a desktop application that allows developers to convert a 3D scan of an environment into a Vuforia Engine dataset. This dataset can be used as Area Target in a Vuforia application to recognize a specific environment and to augment it with information placed in 3D.

Google Glass, regarded as one of the earliest commercial AR glasses developed by Google, can provide see-through screen and display simple contents on one eye. Google Glass displays information to the wearer using a head-up display. Wearers communicate with the Internet via natural language voice commands[36]. Google glasses were widely used and research. Rehman compared augmented reality-based indoor navigation application to assist people navigate in indoor environments[37]. Yamaguchi presents the MVP (Musical pitch Visualization Perception) support system for smart-glass and compared the difference between smart-glass and conventional tuner.[38]

1.4.3. Mixed Reality

A well-known taxonomy that was coined by Milgram et al. defines MR among other technologies such as VR[39]. The model states that MR is a technology that consists of amalgamating 3D content and the real-world environment. In contrast, VR is a single virtual environment isolated from the real world[40]. In recent years, new devices have emerged and changed the concept of MR applications. A new taxonomy created by Bray , redefines the capabilities of the MR headset[41]. These new models incorporate improved sensors and the capability to communicate with multiple users in the same environment simultaneously and change the relationship between the physical and virtual environment in MR technologies, such as spatial mapping for Microsoft HoloLens [42] and The Mirror World[43].

These accessibility features offer a wide range of application development opportunities and research explorations into user experience (UX) of the Microsoft HoloLens HMD. VR applications are examples of other spatial 3D user interfaces [44]. However, in non-see-through VR HMDs, the user cannot perceive their actual physical surroundings [45]. An advantage of implementing spatial MR UIs over the standardized VR digitized screen is that MR is visually less-restricted than the physical boundaries of the VR screen. Furthermore, spatial MR UI permits users to freely explore open spaces[46]. The spatial mapping feature of the HoloLens is suitable for creating MR UI for location-aware applications[47]. The standard HoloLens UI acts as a virtual spectrum between the user and the physical environment. Therefore, MR HMDs like the HoloLens is more effective than VR systems for developing interactive spatial UI environments. Collaborative visual interfacing across the HoloLens platform allows simultaneous group interactions and engagements to create shared visceral experiences. However, a critical factor in enhancing the user’s natural ability to interact within the MR environment concerns the measuring of distance travelled, the manipulation of objects and other environmental factors such as the navigation of physical obstacles [48].

Figure 1.5 Microsoft HoloLens 2

Microsoft HoloLens 2, in Figure 1.5 is an AR-based Mixed reality (MR) headset developed and manufactured by Microsoft, it combinates waveguide and laser-based stereoscopic & full-color mixed reality smart glasses. It uses hand tracking as main interaction way instead of consoles. Compared with other AR glasses, it provides wider range of field of view (FOV), more precise depth sensors, clear screen and detection capability.

While these AR and VR glasses provide unprecedented experience, they also have limitations. Most of these AR or VR glasses are not light enough as a pair of conventional glasses, Resolution of the internal screen are not high enough. Gesture detection level are not high enough. Besides, only limited fields can take high advantage of these technologies, therefore they are not so well-known in the market.

1.4.4. Application in retail industry

Recent advances in Augmented Reality (AR) technologies have led to a growing interest in their application for marketing strategy. It is termed Augmented Reality Marketing (ARM). Customer-facing interface for the application of digital marketing technologies in physical settings. ARM delivers experiences that are valuable to customers in a way that is different from other marketing approaches[49]. AR provides new facilities and interactive content that improve consumer motivation of behavioral intentions[50]. AR marketing influences consumers' behavior intention by increasing decision comfort along with gratifications, and leads to long-term benefits via creating utilitarian, hedonic, and symbolic benefits for users[51].

More researches had been done on augmented reality in areas including marketing, advertising, e-commerce, and shopping centers. Zimmermann developed a shopping assistant application using personalized recommendations and explainable artificial intelligence to consumers[52]. In 2017, Audi launched a VR showroom globally, enable users to check out all Audi's car products and customizing their needs in a VR environment. In 2018, Zara introduced AR technology to its stores for a limited time through exterior window displays and special in-store AR zones[53]. GAP also launched an AR app – Dressing Room - that enables customers to try on clothes in a virtual mirror without taking the time to go into a fitting room or even go to a physical store (APK Mirror). Timberland is now experimenting with augmented reality technologies, using Kinect to recognize buyers and superimpose Timberland clothing and accessories on them, allowing them to browse the catalogue and choose their size[54]. In the brick-and-mortar supermarket and convenience setting, augmented reality is typically employed for product information displays and navigation. Despite the fact that studies on virtual stimuli based on augmented reality were undertaken, most augmented reality devices were smartphones or projector displays.

1.5. Research Purpose

Although brick and mortar supermarkets and convenient store are facing challenge from online shopping service, they are still irreplaceable in many aspects. To further enhance competitiveness, new technologies are being used to improve customer shopping experience, but limit applications were on shopping atmosphere. While VR, AR and MR technologies are widely adopted in the field, there are several limitations: 1) some of them are applied in online supermarkets to improve the sense of products instead of stores. 2) in-store atmospheric applications are applied in smart phones or display monitor, which can only provide immersive atmosphere in certain place or provide on little screen. 3) real atmospheres were being designed, but only one atmosphere can exist at the same time.

My system aims to bring multiple interesting shopping atmospheres to daily brick-and mortar shopping by using AR HMD—HoloLens 2. Compared to real atmosphere, virtual atmosphere can create multiple atmospheres at the same time, so that multiple atmospheres can be designed to satisfied different customers' preference. And with the use of HoloLens 2, customers can see the atmosphere of whole brick and mortar supermarket or convenient store in front of eyes. After designing the AR system, I would like to verify if AR atmospheres in brick-and-mortar store can influence on emotional feeling and shopping preference, therefore shed a light on if AR technology can show possibility to attract more customers back to brick and mortar supermarket and convenient store.

2. Related Researches

2.1. In-store atmosphere design

Over last decades, brick and mortar stores are adopting new services for consumers. Products diversity is an important perspective, providing more choices for consumers, and one-stop shopping instead of visiting many places. Products uniqueness is also an important way, providing irreplaceable goods for consumers. Except for products, services play a more important role in modern retail. Shopping malls with diverse kinds of stores gather together to attract customers with different needs into a same place, including apparels, makeups, supermarkets, electronic products, cinema, dinning, beauty and etc. Stores with fitting decoration generate good atmosphere and thus attract customers attention. Store decoration and atmosphere are getting more important for better experience in nowadays' fierce competition.

Atmosphere fit in brick-and-mortar store have long been researched in the past few years. Some scholars focus on what kinds of elements impact more on shopping experience. Some scholars compared pattern of online store and brick and mortar store to distinguish which elements determined users' choice to shop offline. Also, there are researches on store's chain store's atmospheric consistency, and thus forming customers trust level. Store atmospheric factors have significant positive correlation with customer approach behaviors, design factors being the most significant impact among all factors. Store atmospheric factors will influence not only customer emotions but also customer cognitive valuations of commodities and services[55]. Researchers found indicate that atmospheric variables such as cleanliness, scent, lighting, and display/layout have a positive influence on consumers' purchase intention[56].

Baker considered that the design of business environment could produce unique emotional impacts in customers' minds and could increase buying possibilities. He divided environmental factors into three categories:(1) Ambient cues, that is, the ambient conditions that could influence customers potentially, such as attributes of temperature, music, noise and lighting; (2) Design cues, referring to those aesthetic feelings that could be perceived by customers directly, including style, layout and architectural etc.; (3) Social cues, referring to factors related to people in the environment, including customers and store employees. The number, type and behavior of people are proposed to influence customers' perceptions of stores[57]. Bitner separated physical environment into three categories: (1) Ambient conditions, that is, the intangible background features in the environment, including background music, noise, temperature, lighting and odor etc., which would affect people's perceptions; (2) Spatial layout and functionality. Spatial arrangement means the layout of mechanical equipment, facilities, furniture and furnishings etc. as well as their spatial correlations; (3) Signs, symbols and artifacts, that is, signboards used for communicating with customers directly or indirectly and the decorations/designs for store image[58]. Berman and Evans made revisions and supplements to Bitner's (1992) conclusions[59]. They summarized environmental factors into four categories including the exterior of the store, the general interior, the layout and design variables, and the point-of-purchase and decoration variables. Turley and Milliman extended Berman and Evans' (2009) method of classification by adding Human variables, dividing the 58 kinds of environmental stimulus variables into 5 categories: (1) External variables, including exterior signs, entrance, exterior display window, architectural style and surrounding area; (2) General interior variables, including flooring and carpeting, lighting, scents, music, temperature, cleanliness, wall composition and color schemes; (3) Layout and design variables, including space design and allocation, placement of equipment, grouping of merchandise, waiting rooms, waiting ques and furniture; (4) Point-of purchase and decoration variables, including products displays, point-of-purchase displays, signs and cards, artwork, and price displays; (5) Human variables, including employee characteristics, employee uniforms, crowding, customer characteristics and privacy[60].

2.2. Atmospheric psychology

The notion that store's atmosphere influences consumer behaviors was introduced to marketing research by Kotler, who initially defined atmosphere to be a component of store image along with other variables, such as brightness and crowding[61]. However, most research on store atmosphere today builds on the Mehrabian-Russel model, which is at the heart of a research stream called 'environmental psychology' and was first applied to retail settings by Donovan & Rossiter[62] . Environmental psychology is concerned with "(1) the direct impact of physical stimuli on human emotions and (2) the effect of the physical stimuli on a variety of behaviors, such as work performance or social interaction" [63].

Mehrabian considered, a notion which has been ignored by the large majority of studies to date. He suggests that a consumer's response will be mediated by the individual's ability to select among incoming stimuli. The model assumes that the environment influences a person's emotional state, which can be described along three orthogonal dimensions Pleasure-Displeasure, Arousal-Nonarousal and Dominance-Submissiveness (the PAD model). Pleasure indicates the degree to which a person is happy, pleased, satisfied, contented, hopeful, and/or relaxed. A person would score high on the Arousal construct if he/she is frenzied, jittery, aroused, stimulated or excited. Dominance refers to the extent to which a person feels in control of the situation and is able to act freely in the environment [64] Two of the emotional states, namely pleasure and arousal, appear to interact with each other. With a pleasure of close to zero (neutral), a moderate arousal causes a positive response and very high or low levels of arousal cause a negative response in the Stimuli-Organism-Response taxonomy. However in an unpleasant environment (negative pleasure), the higher the arousal, the more negative the response[63].

The three emotional states determine and mediate the environment's effect onto the response which can be either approach or avoidance type behaviors. For example, consumers responding positively will want to spend more time in the environment, want to look around and interact with other individuals present. It will lead to enhanced performance or satisfaction[63]

A wider perspective towards modelling store patronage was suggested by Monroe and Guiltinan. Store patronage is largely determined by purchase needs and purchase habits, but then influenced subconsciously by the consumers perceived retail store types and characteristics.[65]

2.3. Customer shopping intention

Intention refers to a user's predisposition towards using an online shopping store in the future. Customer's shopping intention is potentially influenced by many factors, many researchers are working on to modelized or clarify what kinds of elements impact shopping intention. Shopping intention including intention towards products, towards store, toward services toward purchase process, and toward social intention. While approach behaviors refer to all positive actions that might be directed toward a particular setting, for example, intention to stay, explore, and affiliate, avoidance behaviors concern the opposite (Mehrabian & Russell, 1974). Donovan and Rossiter (1982) adopted time and money spent, returning, store exploration as their approach behaviors. Dholakia built a framework of important factors to understand shopping behavior: sex, shopping contexts, shopping responsibility, gender role, shopping motives, shopping pleasure, interaction with family, utilitarian, enjoy of shopping to the supermarket and the mall, social reinforcement. Curiosity

[66]. Spies proposed the atmospheric factors, i.e. their condition, information rate and layout, can positively improve shopping mood, and therefor spent more money[67].

Valuable product and service as a main factor, determined customer's purchase intention. Ladhari reported that perceived service quality (reliability, responsiveness, assurance, and empathy) and service environment (atmosphere and layout) both increase positive emotional satisfaction[68]. In turn, positive emotional satisfaction leads to a high perception of product quality, high recommendation, patronage intention, and likelihood of purchase.

Curiosity is defined as a part of the shopping experience as an affective reaction[69], or a part of the flow concept. For example, Huang considers flow as a multidimensional construct including control, attention, interest and curiosity[70]. Moreover, Pace and Agarwal and Karahanna defined curiosity as an antecedent of the flow which contributes to decrease the cognitive charge of an immersive experience[71]. However, according to psychologists, curiosity is an intrinsic motivation for consumer and seems to be the most relevant variable to explain the exploratory behavior of consumers[72]. Koo verified Perceptual curiosity moderates the relationships between atmospheric cues (i.e. graphics, colors, links) and shoppers' emotional reactions, and further impact on shopping intention[73]. Beek used a virtual fitting rooms for customers, showed that the presence of perception design significantly increases specific curiosity about the product, intention to patronize and intention to purchase.[74]

Grewal demonstrated the number of visible store employees, numbers of customers, a music elements have strong relationship with patronage intentions[75]. Shopping intention of certain characteristics customers were also being researched: For Generation X and generation Y, consumer's shopping intention was affected by perceived benefit, store characteristics, perceived risk and perceived pricing. Rajamma claimed the Generation Y consumer's uniqueness need is an important factor for retail patronage[76].

Contemporary society has been described as a culture in which commodities are consumed not only to satisfy needs or wants but also to construct a social identity and structure interpersonal interactions[77]. Consumption has become, for many, a fundamental aspect of daily life[78]. For example, research by Midgley, Dowling, and Morrison found clothing purchases to be affected by social referent influence, and this influence varied by characteristics of the consumer[79]. The determinants of certain shopping activities were investigated[80].

These scholars' researches highlighted attractiveness, curiosity, individual preference's difference, interpersonal interaction and patronage in their research. In this thesis, I would like to take these factors as part key indicators of shopping intention.

3. System analysis and design

Overall, this system aims to increase brick-and-mortar supermarket revenues by improving customers' shopping experience with mutual virtual atmospheres using VR/AR devices.

Brick-and-mortar supermarkets and convenient stores act as high frequency scenes in daily life, providing daily necessary goods for surrounding customers. In big cities, supermarkets and convenient stores face fierce competition, targeting at different layer of customers, and providing customized products and services. Conventionally, utility function is the main function of supermarkets and convenient stores, which means customers tend to buy products rationally, choosing products based on what they need. However, providing hedonic value are becoming more and more important. I am thinking about providing pleasure emotion for supermarkets and convenient store customers. In Japan, especially around Tokyo, Ito Yokato, Tokyu Store, Maruetsu, Seiyu, Seijouishii, OK store are common chain supermarkets, 7&11, Lawson, Family Mart, New Days are common convenient chain stores. To distinguish oneself from others, inner decoration, products combinations, deliver services are main approaches. For convenient stores, products collaboration with third-party IP characters or time-limit sales characterizes oneself from another.

Inner atmospheric variables are significantly important for store formats, impacting consumers hedonic feeling and therefore impact shopping preference. But inner decorations cannot be change frequently, due to consistency of chain stores and limitation of decoration cost. Mixed reality, as a technology to display certain virtual contents on real environment, provide possibility to alter inner atmosphere into diverse kinds of looks.

Both augmented reality, virtual reality, Augmented Reality technologies are mainly widely used in entertainment field or education field, although they brought interest or immersive experience, current appliance scenes are limited. I am trying to figure out if virtual atmosphere can be impactful to consumers emotion and shopping preference, and what kinds of virtual elements acts as influence factors.

3.1. Stakeholder analysis

For consumers, utility and hedonism are two main orientations in shopping. In supermarket case, products and services should satisfy basic utility purpose in a supermarket, then consumers are looking for better hedonic values. I developed an atmospheric system to satisfied hedonic requirement. Consumers who visit the brick-and-mortar supermarket are assume to enhance their pleasure level, feel satisfied with the products and supermarket.

Overall, I assume in the experiment, customers can impact shopping preference and bring more revenue for supermarket.

3.2. Current supermarket investigation

In this part, I investigated several supermarkets and convenient store in Guangzhou, China, to figure out what kinds of atmospheric design they are adopting, and how they take advantage in their service field and maintain customers. The targets stores are AEON, CR Vanguard, Fresh Hema, Shengjia supermarket and C-store convenient store. Basic information is as following Figure 3.1.

Store	AEON	Vanguard	Fresh Hema	Shengjia supermarket	C-Store
Location	Inside shopping mall	Close to residential area	Both residential area and business area	In residential area	Almost everywhere
Space	Large	Middle to large	Large	Small to middle	small
Size	9 province	All country	Big cities	In area	In area
Price level	Middle	Middle	Expensive	Low to middle	middle
Target customers	All age	30s or elder	20s˜40s	residence	White collar and residence
Characteristics	Long time operation	Convenient, abundant choices	Fashionable, Online to offline	relation arrangement with residence	A large amount of stores everywhere.

Figure 3.1 Supermarket comparison

To design a proper virtual atmosphere for supermarket, I focused on several parts of atmosphere and compared the difference among stores: lightning, arrangement, background music, and specific showcase.

In almost all the stores, lights are shed on food and vegetable. Direct light from the top or from the refrigigator highlight the colorfulness and freshness of them. For vegetbale in Figure 3.2and frozen meat in Figure 3.3, cold color light were adopted in Vanguard and Fresh Hema,while for fresh meat, warm color light were adopted in Shengjai supermarket.

Figure 3.2 Lights Shed on vegetables

But for package snacks, although they are all eatable, light is not necessary due to long-term expiration date. Also, for some advertisement products in Figure 3.4, lights were also used to attract customer’s attention compared to non-advertisement products.

Figure 3.3 Lightning Arrangement of Meat

It is interesting to find most of lights effect were adopt for food products instead of daily-use products. For convenient store, C-store, large numbers of their products are food, beverage, snacks, with little amount of daily use products and stationary. Because of limit space and concenterated products arrangement, overall warm lights were adopted to maintain the consistant design of the store.

Figure 3.4 Lights on Advertisement Products

Different store have specific arrangement style: food are always being placed in most interesting way. Snacks such as fried potatos and cakes have colorful package, while they are placed together, customers can feel diversity and richness of product selection. It is also interesting to see in Fresh Hema store, coconut in Figure 3.5 are placed together with coconut trees, Frozen beef are placed together with wine, oranges and tomatos are placed on the top of basckets in Figure 3.6. Flowers in Figure 3.7 are placed in an interesting manner, although product themselves are the same, the atmosphere of garden strength the feeling of freshneess. Thes arrangement can suddenly awake customers instinct feeling, feeling immersive into a origin location of accroding products.

Figure 3.5 Atmosphere of Coconut

Figure 3.6 Atmosphere of Fruits

QR code here in AEON in Figure 3.8 were designed to help customers better realized the product information. Although it provided information, only few numbers of customers paid attention to the designed. This is probably because customers need to take out of certain device like smartphone and scan by cameras. The interaction itself is not convenient and the QR code didn't mention attractive information to users. So personally, I don' think the QR code design is valuable enough.

Figure 3.7 Atmosphere of Flowers

After investigating and analyzed the atmosphere design in these stores, I found the common sense of these arrangement were set in food area or fresh products, implicating the designed in these parts can significantly impact customer’s shopping intention. In the following design, I would like to apply more atmospheric element on food or fresh product areas.

Figure 3.8 QR code of Products

3.3. Subsystem analysis

3.3.1. Scene system

In conventional supermarkets, same chain stores tend to adopt a common-share decoration. There are many advantages: 1) characterize the brand, emphasize a common internal impression. 2) standardize a common style helps decrease decoration design cost, reduce internal shelves and devices wholesale prices. 3）quickly applied in new-open store and start operation.

Disadvantages also exist, for example, 1) since the decoration style of each brand of supermarkets is fixed, customers would get used to the scene, somehow paying less attention inside the store. 2) customers in different age are facing same decoration. Customers with personal preference may change their patronage store if find another fitter store, because designing specific decoration for specific customers are impossible.

With the use of Augmented Reality, inner decoration can be designed into uncountable number of styles. Common characteristics among chain stores are for sure, except for that, decoration can be set to awake different emotional feelings. For example, for younger buyers, generating exited atmospheres can be attractive: if generate exited mood, an amusement resort, Disneyland, USJ park or other theme park are available, if generating silent mood, an aquarium or an art museum are available, if generating stimulated mood, a ghost house can be available, if generating mystery mood, a universe scene can be available.

Besides, all the virtual atmosphere elements, compared to conventional decoration elements, are more vivid, assembled with animation, jiggle, appearance changing and interactable. For example, a virtual monkey can be placed inside the supermarket, and vividly walking and jumping around inside the space, virtual Christmas trees can juggle at a nature frequency cutely. Also, according to device's capability, Figure 3.9 shows MRTK[81], an SDK of HoloLens 2 provide possible for users to touch, grasp or twist the virtual atmosphere elements, which provide an interactable functions and bring more interest for customers.

Figure 3.9 Interactable with virtual objects

In my experiment, I tried combined daily shopping scene with non-daily extraordinary atmosphere together, take advantage of virtual atmosphere and generating a scene which is barely seen. It should be fresh enough, bring exiting feeling, happy feeling or wideawake feeling etc. After collecting data and according models used in the system, and analyzing the possible of fitting in certain device, I chose the universe, undersea world, crazy candy park, snowy Christmas villa are chosen as my initial target scenes in the following steps.

3.3.2. Supermarket environment subsystem

After long years' operation, chain supermarkets brands had already implemented a mature management methodology, King and Jacobson summarized supermarket management factors into six key management areas: (1) supply chain practices, (2) human resource practices, (3) food handling, (4) environmental practices, (5) quality assurance, and (6) service offerings. Environmental practices, as a core part of this system, are being maintained to a stable state.

It is important not to destroyed the current stable environment as well as to place new virtual environment atmosphere elements in a certain place, so I consider placing virtual elements in a wider space, especially on the top of shelves, gap between shelves, and on the concise walking passage. Thanks to the capability of area recognition, virtual elements are not necessary in a certain range of place but movable, thus elements can be more vivid, and bring more fun.

Compared to conventional brick-and-mortar supermarket or convenient store, using VR/R can change the overall light color, and generate a feeling of outdoor. For example, VR make it possible to generate an undersea supermarket, with bubbles everywhere, sunlight refracting into sea randomly, blue become main color of the whole scene. While adopting AR in brick-and-mortar supermarkets, virtual snow can be designed and put in the whole scene, thus forming the winter feeling.

3.3.3. Useability subsystem

Since this system is applied in supermarket or convenient store, which is a high frequent daily scene, the system should consider the balance between customers' shopping behavior and devices usability. In former research or business adoption, customers can scan QR code next to certain products with smart phones, AR context or figure would help customers realize related information. This movement requires customers to use one hand carrying smartphone and targeting at a small code image, which spends a lot of movements carrying out and scanning, and also need the use of one hand, thus limits the convenience, heighten the hurdle, thus reducing using willingness.

Ideally, customers can shop around with two spare hands, using simple and light glasses without any burden, they can easily check products and relate information just by eye focus, when they want to check 3D shape of both real or virtual objects, hands can easily move or rotate it, surrounding environment and atmosphere are widely perceivable inside the supermarkets. Here I highlight two points available in current technical situation: 1) shopping with hand free and real and 2) real and virtual environment widely perceivable. 3) consumers can interact with both real and virtual objects. To free customers' hands, I used Head-mount display (HMD) as main experiment devices. Cameras inbound make sure customers can check specific target just by moving their head or eye focusing direction, therefore customers can use the hands to carry products.

3.4. Experiment design

Former researchers have already researched on impact of emotional feeling on shopping intention, but few of them used virtual atmosphere as influence factor. Exciting atmosphere, in the thesis, refer to atmosphere which is unable to experience in the real life, or multiple attractive atmospheres at the same time. To discover how exciting virtual atmosphere in brick-and-mortar supermarket or convenient store impact consumers' emotional feelings and shopping preference. I divided the experiment into 2 steps:

Experiment 1) Designing an atmosphere which is unable to experience in the real life, and verifying if virtual atmosphere can impact emotional feeling as well as shopping preference in VR environment. In this experiment, environment, atmosphere elements and products are virtual, subjects cannot buy any products in this circumstance, so only survey their emotional feeling and shopping preference.

Experiment2) Designing a system which contain multiple attractive atmospheres at the same time. Atmospheres applying multiple virtual atmospheres in brick-and-mortar convenient store and figure out what kinds of emotional feeling is awaked and thus generate what kinds of shopping preference in AR environment. In this experiment, environment and products are real, but atmosphere elements are virtual, subjects are able to interact with both real products and virtual atmospheric elements, thus my survey can not only analyze emotional feeling but also shopping preference.

4. Experiment 1: VR experiment

4.1. Prototype design

First experiment is applied in VR environment. Because everything in VR environment is virtual, there was no need to consider the real obstacles (i.e. limit space, light limitation, height limitation, products amounts, realistic layout limitation). The purpose is to design an exciting scene or place once I heard of the name. Usually, I would like to say Disneyland, the universal UFJ world, aquarium, science museums or Doraamon's home. Due to copyright limitation, here I designed an undersea supermarket similar to aquarium. Virtual environment allows users to image shopping undersea which is almost impossible in real world. Customer can feel they are able to breath in mystery sea, walking and shopping like creature inside. Like in Figure 4.1, Figure 4.2, Figure 4.2users can walk on a stone road, closely observe vivid corals and seagrass, Figure 4.4 shows fishing swimming next to users even more strengthened the atmosphere. Lastly, a background music was also chosen to improve the immersive feeling. The background music is ocean breath.

Figure 4.1 Undersea Supermarket

Figure 4.2 Sea Grass Figure 4.3 Fish swimming

Figure 4.4 Corals, Seagrass and Bubbles

To compared atmospheric impact on subjects, a normal-like virtual supermarket are also set as control group. Like in the Figure 4.5, except for lightning, music and aquarium elements, other elements like space size, shelves, products are the same.

Figure 4.5 Conventional Supermarket

4.2. Device Selection

Currently main VR devices are Oculus Quest2, Oculus rift, HTC Vive, PlayStation VR. Oculus Quest 2, HTC Vive need a high spec computer as core processor, and extra 2 TOF sensor to detect users' motion. These characters limits experiment moving distance, possibly lead to recognitional error and require higher computer specs. PlayStation VR is a platform mainly in Sony PlayStation, as a mainstream gaming VR device, require a relatively special game developing environment different from other devices. HTC Vive have released for many years, although it was still widely used in entertainment fields, VR new functional features' support for the device is absent. Oculus Rift and Oculus Quest 2 are all released by Oculus, while Rift doesn't embed computing processor and Quest 2 embedded Qualcomm XR2 inside. Compared to Rift, Quest 2 is a new released devices which integrated motion sensors in device, providing internal processors, and fit well with main stream development environment. These features made Oculus Quest 2 a suitable device for the experiment.

4.3. Developed environment

In this experiment, Unity was used as developing engine, develop version is 2021.3.15. The engine can be used to create three-dimensional (3D) and two-dimensional (2D) games, as well as interactive simulations and other experiences. The engine has been adopted by industries outside video gaming, such as film, automotive, architecture, engineering, construction, and the United States Armed Forces. The Unity editor is supported on Windows, macOS, and the Linux platform, while the engine itself currently supports building games for more than 19 different platforms, including mobile, desktop, consoles, and virtual reality.

The Oculus Integration SDK for Unity provides support to develop Oculus apps in Unity, the version is 46.0. The Oculus Integration brings advanced rendering, social, platform, audio, and Avatars development support for Oculus VR devices and some Open VR supported devices.

As mentioned in the former part, Oculus Quest 2 embedded core processor inside to run application. However, in the supermarket scene, virtual objects numbers are over expected, light effect in aquarium also require higher spec for rendering. We first tried installing the system in Oculus Quest 2, and monitoring the running situation if it is proper for experiment. I first tried running the application, but the frame rate was terribly bad, cannot make sure basic movement smoothly. Results in Figure 4.6 reveals the running display rate, delay rate. Obviously, this scene is too complex for mobile processor.

Figure 4.6 Operation Situation (Before)

To optimize the performance providing better experience for users, I changed my solution adopting PC for running software and use VR device for display and movement operation. This solution can take advantage of PC processor capability, which is ten times better than mobile processor, running smoothly without redesign scene elements and configuration. The experiment PC is Xiaomi G Laptop, with 15GB RAM, AMD R5800H and RTX3060 embedded. Results in Figure 4.7shows the application can run at 30 fps/s or higher. Ideally, user can wear on VR HMD in experiment without cable connected to PC using wireless communication. However, for a more stable performance, cable is used to connected although it limits user's movement.

Figure 4.7 Operation Situation (After)

Overall, the system construction is visualized in the following Figure 4.8.

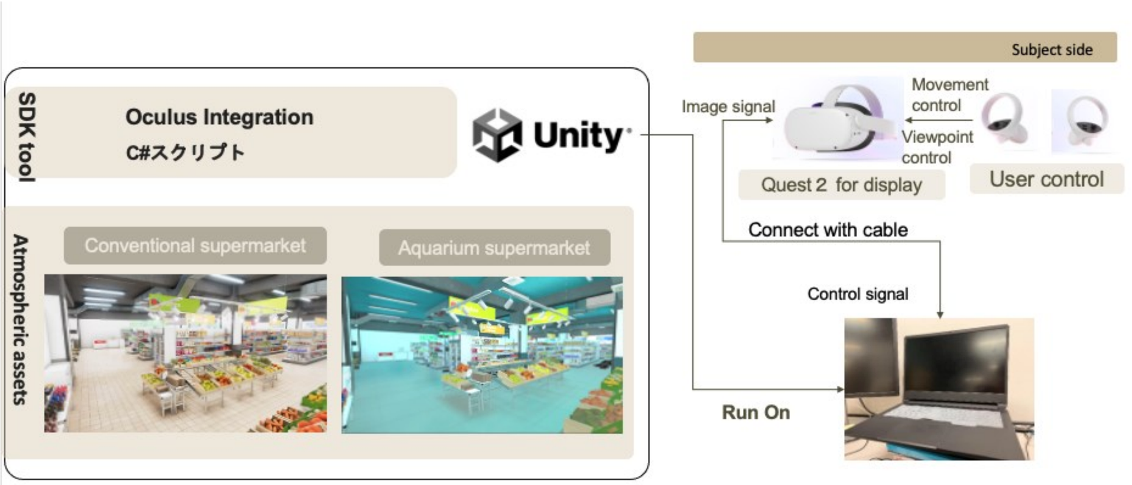

Figure 4.8 VR system construction

4.4. Hypothesis and Indicators

This experiment is to verify if virtual atmosphere of exciting scene can impact emotional feeling as well as shopping intention in VR environment. Compared to conventional supermarket, an exciting atmosphere should awake customer's emotional feeling. Exciting virtual atmosphere elements were listed to evaluate user's perception. I supposed all the exciting elements can awake user's attention and arouse their preference.

H1: Compared to conventional supermarkets, consumers feel more satisfied with exciting virtual atmosphere.

Virtual atmosphere provided customer enjoyable shopping experience without physical constraints and enrich consumers' positive emotions. Virtual atmosphere elements can awake certain positive emotions should be tested. Since the positive emotions are different in different scenes, several emotional feeling descriptions were listed to evaluate user's emotional feeling in the scene.

H2: All the virtual atmosphere elements can result in certain kinds of emotional feeling.

Shopping intentions, refer to all shopping behavior and intention in shopping process. Pleasure feeling are regarded important for shopping perception and shopping intentions. Due to limitation of capability to purchase products in the VR environment, only attractiveness of the supermarket, attractiveness of products, purchase intention, re-purchase intention, patronage intention, willingness to share to friends and willingness to share to family were selected as indicators.

H3-1: Pleasure emotion have positive impact on supermarket's attractiveness,

H3-2: Pleasure emotion have positive impact on product attractiveness,

H3-3: Pleasure emotion have positive impact on supermarket recommendation intention,

H3-4: Pleasure emotion have positive impact on patronage intention.

H3-5: Pleasure emotion have positive impact on purchase intention.

Likert 5 scale was adopted in the experiment and all questions were listed in Table. 4.1.

	Conventional Supermarket	Undersea supermarket
Emotional feeling	Do you feel happy? Do you feel relaxed? Do you feel calm down? Do you like the whole atmosphere?	
Virtual atmospheric elements		Do you like the lightning? Do you like the music? Do you like the product arrangement? Do you like decorations like coral and pearls? Do you like the stone roads Do you like fish? Do you like bubbles?
Shopping intention	Do you think the supermarket is attractive? Do you think the products are attractive? Do you want to recommend the store to your friends? Do you want to recommend the store to your family?	

	Do you want to revisit to the store in the future? Do you want to buy products? Do you want to buy products in the future?
Opinion on VR	Can you get used to Oculus Quest 2? Do you feel more like VR technology? Do you have higher expectation on VR? Do you want other atmosphere in supermarkets? Do you want to go to the supermarket if close to your home？
Subjective questions	How do you feel of the overall supermarket?

Table. 4.1 Questions in VR Experiment

4.5. Experiment process

Subjects were invited into a simple and silent room in Figure 4.9. After confirming description and consent form, subjects are asked to wear an Oculus Quest 2, and confirmed if they can fit in the device.

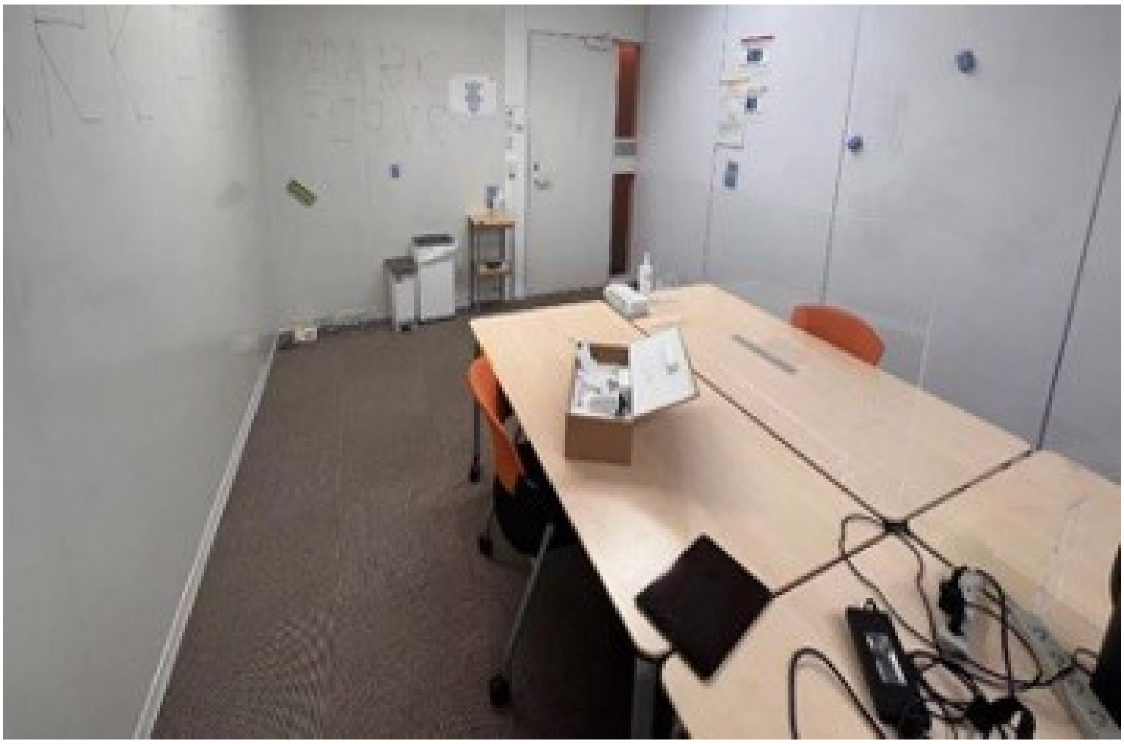

Figure 4.9 Experiment Environment

Then subjects were asked to walk around in the conventional supermarket using consoles, check out products, decoration inside, or whatever they want in less than 5 minutes. Then, Oculus Quest 2 was removed and fill up questionnaire on feelings. After the first questionnaire, subjects were asked to walk around in the undersea supermarket using consoles, check out products, decoration inside, undersea creatures, stone road and everything in less than 5 minutes. This Figure 4.10 shows how subjects experience the VR supermarkets.

Figure 4.10 Experiment Process

Also, a questionnaire is also prepared, but feeling toward VR technology were also added for analyzing VR advantages and limitations in the supermarket scene.

4.6. Experiment result

4.6.1. Descriptive analysis

Figure 4.11 shows 15 subjects attend the experiment, 6 are males and 9 are females.

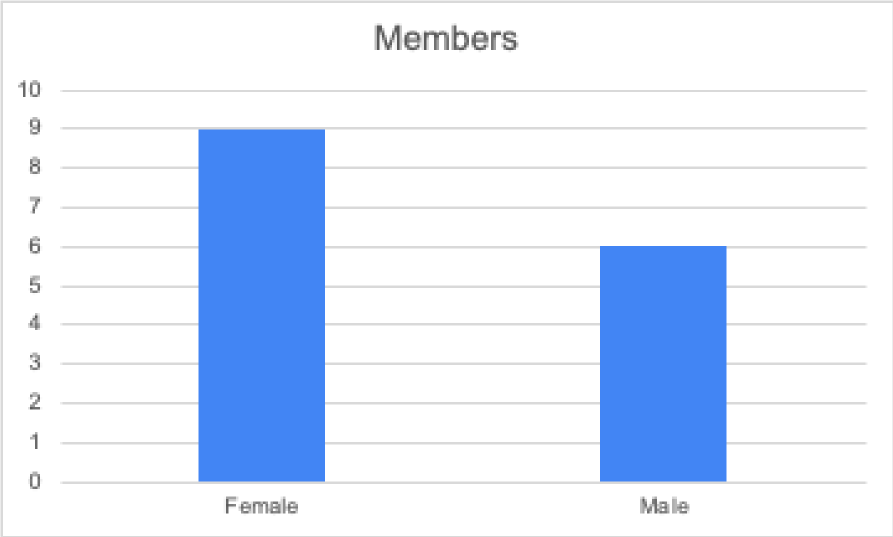

Figure 4.11 Gender Data

Figure 4.12 shows 12 subjects are in 20s, 1 in 30s and 1 in 40s. people in this age tend to be more interested in new technology compared with other ages.

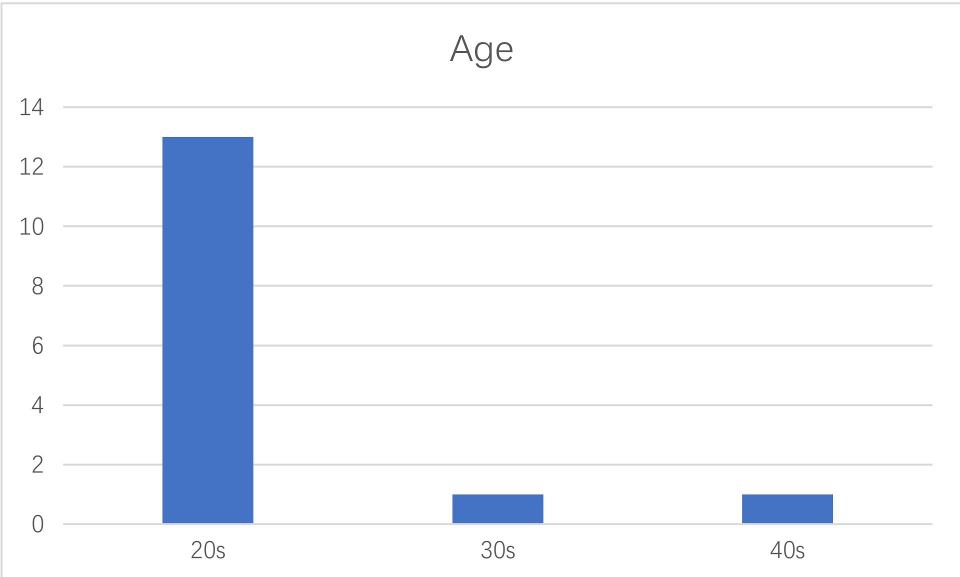

Figure 4.12 Age Data

Figure 4.13 shows average value of all indicators between two scenes, values range from +2 to -2. It is obvious that all indicators in undersea scene have higher score than conventional scene. As we can see from the left 5 rows, emotional feeling tends to be happy instead of relax or clam down, even though the aquarium scene adopts a soothing design. In the right 6 rows, it was interesting to find subjects are more willing to share to friends instead of to family.

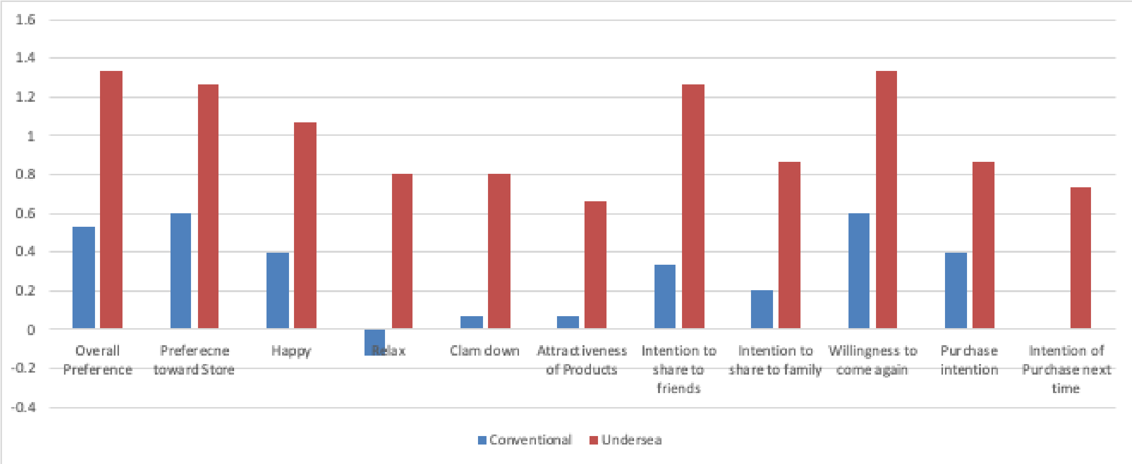

Figure 4.13 Average Data of Indicators

4.6.2. Comparative analysis

First, to verify if subjects' emotional feelings are different in two scenes, I conducted Analysis of variance (ANOVA). Result in Table. 4.1ANOVA of emotional feelings significant level of three emotional states is under possibility of 0.1, indicates happy, relax and clam down feeling between two supermarkets are different, **H1: Compared to conventional supermarkets, consumers feel more satisfied with exciting virtual atmosphere** is supported.

Table. 4.1ANOVA of emotional feelings

Index	Mean Square	F	Sig.
Happy	3.333	8.235	.012
Relax	5.633	6.323	.025
Clam down	4.033	4.193	.040

Next, to figure out if all virtual atmospheric elements result in pleasure emotions, Correlation Analysis is conducted. Results in Table. 4.2 show product arrangement have positive correlation with happy (p.<0.05) and relaxed feeling(p.<0.05). Stone roads have positive correlation positive correlation with happy(p.<0.01), relaxed (p.<0.01) and clam down(p.<0.01). Bubbles have positive correlation with happy(p.<0.01), relaxed (p.<0.01) and clam down(p.<0.01). Fish have positive correlation with happy (p.<0.05). Thus, only part of elements shows close relation with emotional feeling, **H2: All the virtual atmosphere elements can result in certain kinds of emotional feeling** partly supported.

Table. 4.2 Correlation of Virtual Atmospheric Elements and Emotions

		Happy	Relaxed	Clam down
Lightning	Pearson Correlation	0.499	0.430	0.458
	Sig.	0.058	0.110	0.086
Music	Pearson Correlation	0.276	0.213	0.227
	Sig.	0.320	0.446	0.415
Product arrangement	Pearson Correlation	.536*	.578*	0.380
	Sig.	0.040	0.024	0.163
Decoration	Pearson Correlation	0.446	0.454	0.374
	Sig.	0.095	0.089	0.169
Stone roads	Pearson Correlation	.709**	.853**	.737**
	Sig.	0.003	0.000	0.002
Fish	Pearson Correlation	.529*	0.391	0.512
	Sig.	0.042	0.150	0.051
bubbles	Pearson Correlation	.789**	.766**	.760**
	Sig.	0.000	0.001	0.001

Then to figure out if shopping intention between two atmosphere is different, Analysis of Variance was conducted, result in Table. 4.3 shows preference toward supermarket(p.<0.05), intention to share to friends(p.<0.05), patronage intention (p.<0.01), future purchase intention (p.<0.05) have significance. Unfortunately, attractiveness of products and purchase intention have no significance. Intention to share to family without significant variance means shopping behavior of share might be related to sharing target. Unexpectedly, purchase intention didn't show difference, but future purchase intention is relatively high, probably due to products inside VR environment are virtual, and unpurchasable.

Table. 4.3 ANOVA of shopping Intentions

Source	Mean Square	F	Sig.
Preference toward supermarket	3.333	6.087	0.027*
Attractiveness of products	2.700	2.554	0.132
Recommendation to friends	6.533	6.792	0.021*
Recommendation to family	3.333	2.979	0.106
Patronage intention	4.033	10.329	0.006**
Purchase intention	1.633	1.649	0.220
Future purchase intention	4.033	5.965	0.028*

After figuring out indicators differentiated from conventional supermarket, correlative analysis was conducted. Table. 4.4 shows happy emotion have positive impact on all three shopping intentions: Preference toward supermarket (p.<0.01), recommend to friends (p.<0.01), patronage intention (p.<0.01) and future purchase intention (p.<0.01), relaxed emotion have positive impact on all three shopping intentions: Preference toward supermarket (p.<0.01), recommend to friends (p.<0.01), patronage intention (p.<0.01) and future purchase intention (p.<0.01). Clam emotion have positive impact on all three shopping intentions: Preference toward supermarket (p.<0.05), recommend to friends (p.<0.05), and future purchase intention (p.<0.05). All these three emotional feelings have positive impact with revisit willingness. **H3-1: Pleasure emotion have positive impact on supermarket's attractiveness, H3-3: Pleasure emotion have positive impact on supermarket recommendation intention, H3-4: Pleasure emotion have positive impact on patronage intention. H3-5: Pleasure emotion have positive impact on future purchase intention are supported**

Table. 4.4 Correlation between Emotional feeling and shopping intention

		Preference toward supermarket	Recommendation to friends	Patronage intention	Future purchase intention
Happy	Pearson Correlation	.455*	.512**	.704**	.488**
	Sig.	0.012	0.004	0.000	0.006
Relaxed	Pearson Correlation	.556**	.507**	.558**	.560**
	Sig.	0.001	0.004	0.001	0.001
Clam down	Pearson Correlation	.442*	.366*	0.343	.419*
	Sig.	0.014	0.047	0.063	0.021

4.6.3. Imperial Analysis

Subjects' personal subjective opinions are collected in the questionnaire. 10 out of 15 subjects mentioned the undersea supermarket is funny, amazing, interesting. Instead of walling in a conventional supermarket, they also felt like walking and playing in aquarium, an impossible scene in real supermarket.

From the perspective of supermarket, 2 subjects mentioned it is a place for shopping, undersea scene is interesting for sure, especially in amusement product shelves, but for fish and frozen food shelves and refrigerator, vivid fish swimming around might seem wired, thus reducing the appetite of fish products. 1 subject mentioned in conventional supermarkets, informative guidance about in-store products placement is well-prepared. If virtual objects and atmosphere can better introduce products and service, it would be better for customers to make purchase decision among several choices. 2 subjects mentioned the VR supermarket is somehow not realistic, because there are no salesman nor other customers. It is proved that social aspect of human interaction in shopping behavior is necessary.

From the perspective of VR environment, subjects show strong personal preference. 4 subjects feel dizzy in VR environment, although the experiment time was controlled in a short time. Subjects mentioned their preference on cute fish, immersive music, clam down atmosphere, blue undersea lightning, bubbles. While on the other hand, there are 1 subject said too much fish in the scenery, rather, other elements can be simpler to keep the scene attractive. 7 out of 15 mentioned the stone road inside look awful, the virtual stone road objects are too black and without stone details. I found as the virtual scene being attractive, on the other side, subjects looking into more detail, exploring more carefully into the scene.

Interestingly, after each subject experiment, I also had a talk with them. All subjects feel uncomfortable when they wear the VR HMD, but in the comment, they didn’t mention about that. To some extent, I can simply conclude that the pleasure feeling of the scene impact more than uncomfortable feeling.

Finally, 1 subject express willingness to experience more scene except for undersea supermarket, so that each individual can choose a prefer scene according to their current emotional feeling or life state. In the later experiment, I would like to conduct more than one virtual scene for users.

5. Experiment 2: AR experiment

5.1. Experiment design

(Atmosphere design, devices, interaction, subject numbers)

The second experiment is applied AR in real supermarket or convenient store. I am grateful for a convenient store close to campus, one of the third biggest chain convenient store in Japan. Chain convenient store share a similar decoration and atmosphere, sometimes limited products together. It is popular and common enough so that act as a place to verify if virtual atmosphere can significantly change subjects' opinion of a common store. The interior surrounding is in Figure 5.1 Atmosphere of Brick-and-mortar convenient store

Figure 5.1 Atmosphere of Brick-and-mortar convenient store

Different from VR, in AR environment, virtual objects and atmosphere displayed over real world, virtual objects are supposed to be placed in a certain 3-dimensional position, so there was a need to consider the real obstacles (i.e. limit space, light limitation, height limitation, products amounts, realistic layout limitation). In real supermarket or convenient store, spaces are always narrow. To reduce the complexity of virtual objects and real environment, virtual atmospheric elements are imaged to place on the aisle and top of shelves. In the AR experiment, there were hardware display limitations, AR device's display screen doesn't have a wide range of view (FOV), and brightness of the screen is many times weaker than VR devices. That means if I want to adopt undersea scenario into AR environment, the overall blue lightning effect of undersea cannot be correctly show. Unfortunately, I have to use other scenes in my experiment.

The second experiment comprised of 4 parts: 1) conventional convenient store without HoloLens2; 2) Candy Park theme with HoloLens 2; 3) Christmas festival theme with HoloLens 2; 4) chaos park theme with HoloLens2. Part 1 works as a control group, Part 2 and Part 3 works as an exciting atmosphere to awake users' pleasure feeling, but each individuals have preference, part 2 and part 3 can provide subjects multiple choices to use to prefer scene. Part 4 works as an atmosphere trying to bring different emotional feeling to users by using chaos atmosphere. In this experiment, I am possible to figure out different emotional feeling impact on shopping intentions.

This time I want to generate exciting feeling by designing a cartoon style atmosphere, bringing user into a cute world and imaging oneself as leading role in a story. Here I adopt a candy park as main atmosphere, see Figure 5.2.

Figure 5.2 Candy Park

Rainbow roads are placed on the real isle, cakes and candys can be grasp, amplified, shrink or move (Figure 5.3). Cute candy knights jiggling on the ceiling of the convenient store, standing for the establisher of this candy town (Figure 5.4). Candy wrapper rain are also designed into the scene, for generating unprecedented experience.

Figure 5.3 Interactable Cake

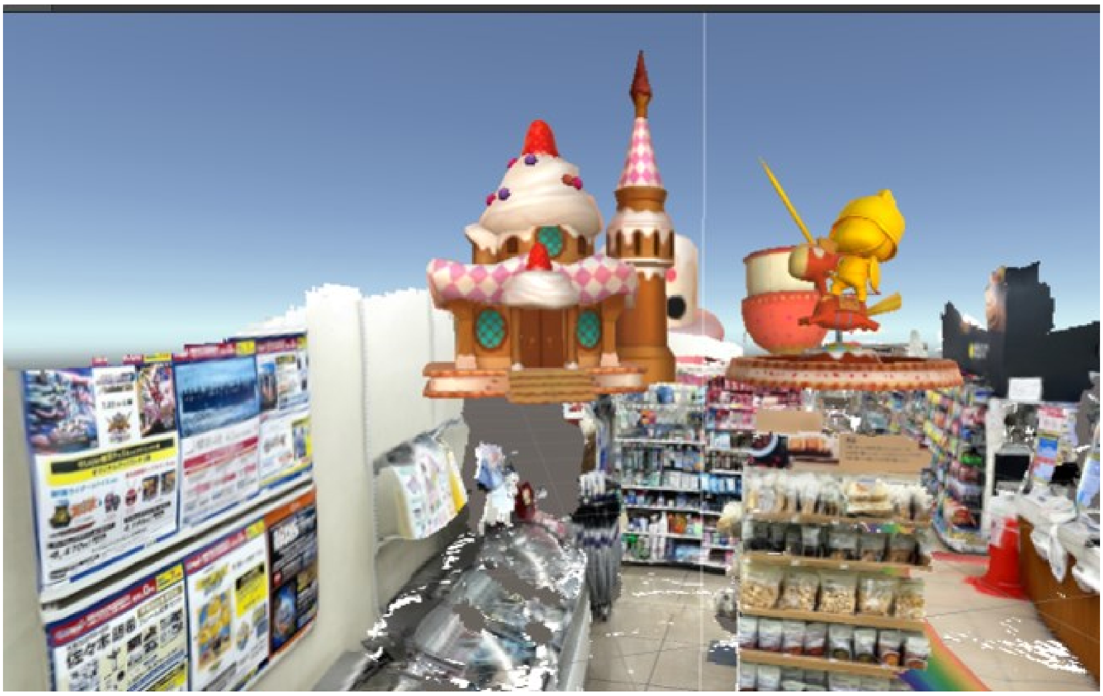

Figure 5.4 Candy Knight on the Ceiling

Due to imperial cues of individual preference, another scene is also needed. Different from an amusement park, I was wondering if a festival scene in the certain period can easily awake subjects exciting emotions. Here I designed a Christmas atmosphere (Figure 5.5).

Figure 5.5 Christmas

Snow falling down into the AR world even more emphasize winter's feeling. A family of four snowmen a bit far away in the scene made the supermarket more harmony (Figure 5.6).

Figure 5.6 Snowman Family

Christmas stockings (Figure 5.7)as a symbol, are decorated on spare wall. Christmas trees, although not small, were placed in spare space and set to the same heigh in order to fit into interior space.

Figure 5.7 Christmas Stockings

Virtual fried turkey (Figure 5.8)was placed on a desk in the scene, users can catch the turkey and do whatever they want. Gifts, as exiting elements in Christmas, I stacked 3 huge gift boxes together to attract customers, users can grasp the box and checked it out (but unboxing unavailable).

To better fit in Christmas atmosphere, I held the experiment at the end of December.

Figure 5.8 Fried Turkey

Currently, almost all the commercial supermarkets and convenient store are creating positive decoration. AR Environment provide a possibility to create a negative decoration, to figure out if AR environment can awake different kinds of emotion thus further leading to any shopping behavior. Here I chose a chaos park based on candy park, the appearance and animation of atmospheric elements were revised into wired states: rainbow roads were not on the road but floating on the air (Figure 5.9).

Figure 5.9 Weird Rainbow Road and Castle

Candy trees are jiggering in a quite high frequency (Figure 5.10), candy knights were vibrating, candy castles were set to an unusual proportion. shows the appearance of the scene Figure 5.11.

Figure 5.10 Candy Trees are Jiggering

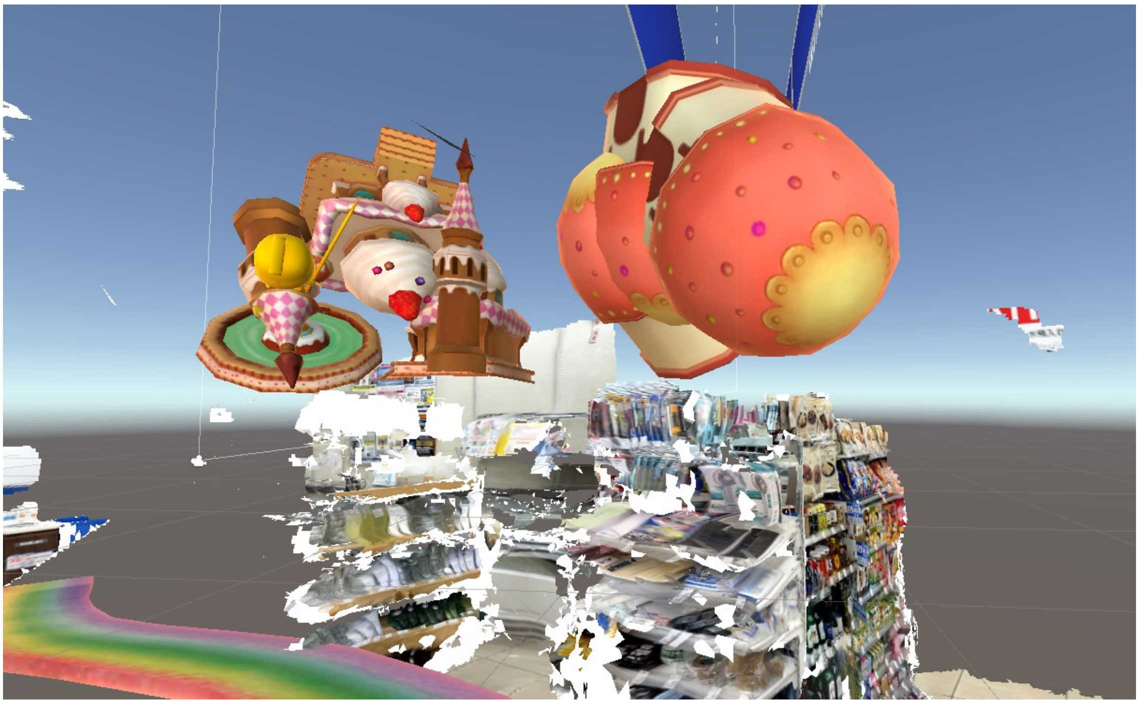

Figure 5.11 The Messy Placement

5.2. Device selection

Because brick-and-mortar convenient store are already arranged in a compact manner, adding atmosphere to fill up limited spare space is an inaccessible solution. Even though, it is still possible to add elements on the road, on the corner, elements next to products, and snow effects on the air. To create a immersive atmosphere covering the whole view, instead of smart phone with small screen or multiple projectors with complex configurations, in this experiment, a head-mount display is to be applied, so that users can move freely and see widely. Typically, there are two kinds of AR HMD devices: video see-through type and optical see-through type. Video see-through type uses graphic data from cameras and displays contents, which have limitation: customers cannot see products as real as real products, especially when checking out the details. Comparatively, Optical-see through type is better, providing virtual contents but also allows customers to interact with products as usual. Whatever the type it is, the field of view should be wide enough, the screen should display colorful, graphic information, so those AR glasses with barely textual information are excluded. Then, the atmosphere is as a whole system, should keep on displaying atmosphere in the convenient store, those devices that only display contents when recognized certain kinds of target shouldn't be applied in the system. In my experiment, I want an overall space recognition function, so that the AR HMD device can keep tracking on the area target, displaying all contents in the whole brick-and-mortar convenient store. Therefore, area recognition function is a must/Virtual objects are displayed overlapped real environment, so special distance recognition function is needed. Most importantly, the device itself should be as light as possible and shouldn't use cable to connect to other devices. After filtering necessary factors, I finally chose HoloLens 2 for experiment. Besides, from the perspective of customer interaction with atmosphere, the AR HMD device should provide hand tracking functions using depth sensors.

HoloLens 2 (Figure 5.12)adopt a comfort wearable ergonomic design, especially friendly to subjects who wear glasses. Besides, also provide advanced functions for developer and users. Gesture recognition functions embedded allows user to interact with virtual objects using hands, so that subjects can not only check out virtual objects but also catch real products. The display of HMD doesn't cover subjects view, but only slightly grey coating film in front of eyes.

Figure 5.12 HoloLens 2

5.3. Developed environment

In this experiment, Unity was used as developing engine, develop version is 2021.3.36f1c1. The engine can be used to create three-dimensional (3D) and two-dimensional (2D) games, as well as interactive simulations and other experiences. The engine has been adopted by industries outside video gaming, such as film, automotive, architecture, engineering, construction, and the United States Armed Forces. The Unity editor is supported on Windows, macOS, and the Linux platform, while the engine itself currently supports building games for more than 19 different platforms, including mobile, desktop, consoles, and virtual reality.

In this part, all the virtual atmosphere should be correctly placed in certain position, so spatial recognition function is necessary. The first step is to capture the convenient store 3D area information and modeled. Although Microsoft provide area target generator develop SDK, professional spatial capture machine is needed. Vuforia, is a popular and useful virtual reality develop engine, provide area target generator function without using expensive spatial capture machine. This time, the develop version is Vuforia Engine 10.7. Developer is required to register a develop account in portal, then you can simply download an iOS application—Vuforia area target generator and use LiDAR scanner to scan the environment (Figure 5.13), this application can automatically generate an 3D area target file. In this experiment, iPhone 13 Pro Max was used.

Figure 5.13 LiDAR Scanner

With the area target file, developer can see area target sample in Unity like in Figure 5.14. Although in resolution is not high, but HoloLens can capture a part of the model and positioning current location. In practical, an initialization spot should be as clear and colorful as possible.

Figure 5.14 Area Target Sample

After fitting all atmospheric elements into the scene, the application should be built in on the HoloLens2. Here I used an official built in SDK: MRTK version 2.8.2.0 to package into an install. The system structure is as Figure 5.15.

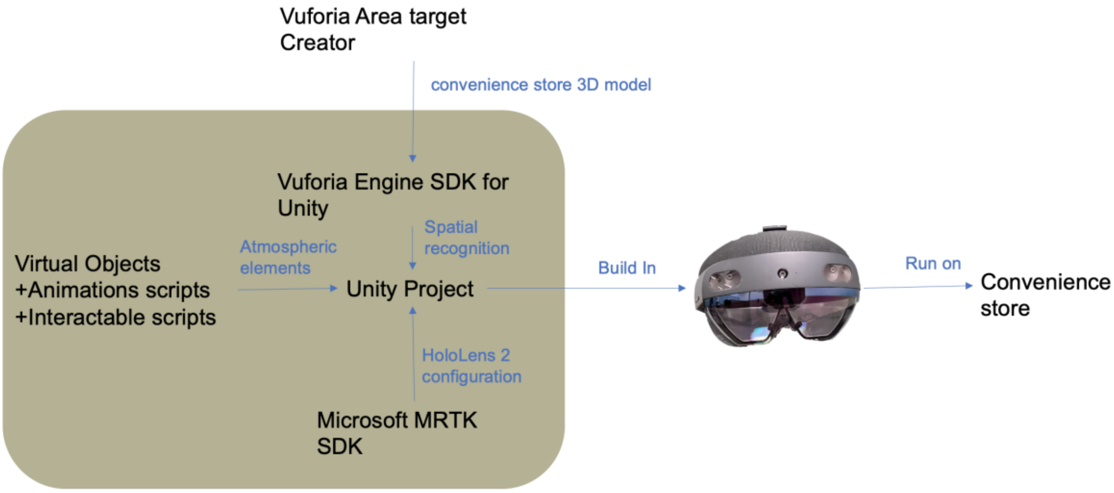

Figure 5.15 System Structure in AR environment

5.4. Hypothesis and Indicators

In this questionnaire of the experiment, indicators comprised of 4 parts: 1) evaluation on atmosphere, 2) emotional feeling, 3) shopping preference and 4) individual opinion towards technology. Multiple-choice question adopts Likert scale for quantitate analyze.

For 1) atmosphere, all these experiments designed virtual atmosphere, includes elements include virtual objects design, animation of virtual objects, interaction of virtual objects and background music. All these four elements are main factors contributed to the virtual atmosphere. Background music, although audio information or music are playing in the store, but the background music here is especially designed for the atmosphere and bring more immersive experience. Indicators of attractiveness of these for elements were evaluated in the questionnaire.

H1: Compared to conventional supermarkets, all virtual atmospheric elements can contribute to emotional change.

For 2)emotional feeling，the system aims to improve shopping experience by bringing pleasure emotion to customers, so main indicators are referring to pleasure level. Since emotional feeling differ from one to one, an objective method to standardized emotions should be adopted. Here I refer

Mehrabian and Russel's model, indicators about atmospheric impact on emotional state: pleasure level and arousal level. All the emotions were supposed to separate into these two axes (Figure 5.16), thus it is possible for quantitively compared difference among subjective.

H2-1: Compared to conventional supermarkets, the exciting virtual atmosphere can result in certain kind of pleasure feeling in brick-and-mortar convenient store.

H2-2: Compared to conventional supermarkets, multiple virtual atmospheres can provide different positive emotional feelings.

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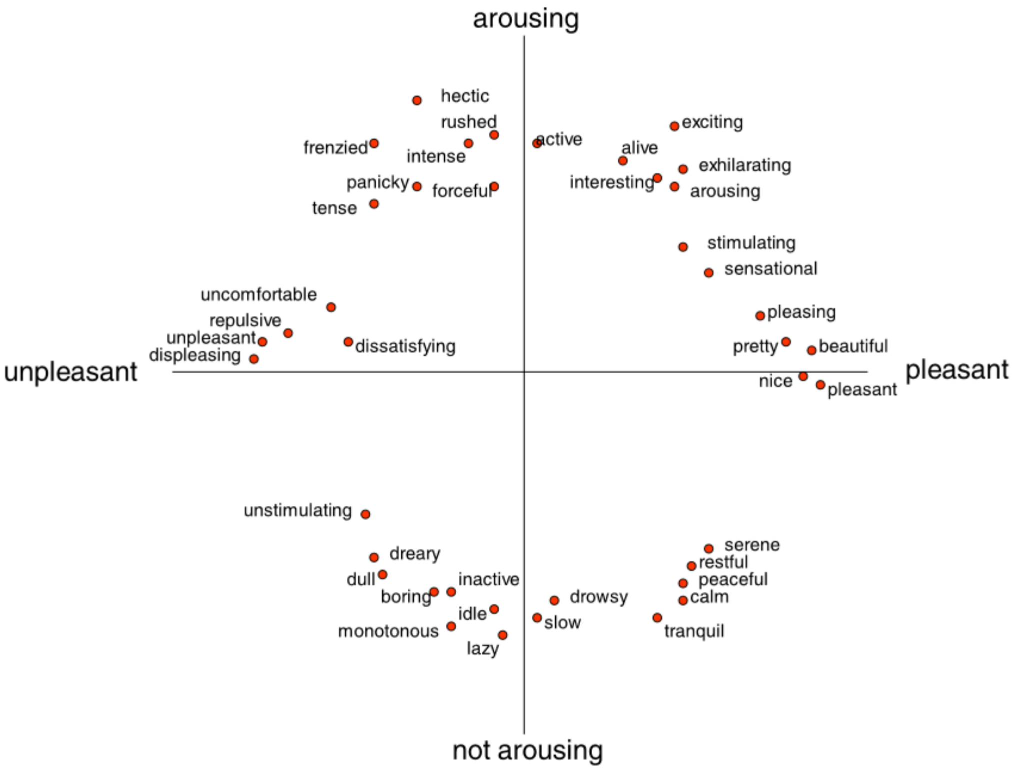

Figure 5.16 Emotion States in 2 Axis

For 3) shopping intention, shopping intention comprised of many parts. In this experiment, patronage intention is selected as a core concept, I mainly focus on patronage intention and relate factors. There or indicator includes attractiveness of products, intention to explore, attractiveness of the store, patronage intention, willingness to share the store to friends.

H3-1: Pleasure emotion have positive impact on attractiveness of products

H3-2: Pleasure emotion have positive impact on patronage intention

H3-3: Pleasure emotion have positive impact on willingness to explore

H3-4: Pleasure emotion have positive impact on willingness to share the store to friends

These prototypes are in a very early stage, limited researches were conducted, so I prepared some questions to realize very individual option toward technology applied. Open question was also prepared, allowing subjective to express anything they thought.

Likert 7 scale was adopted in the experiment and all questions were listed in the Table. 5.1.

Table. 5.1 Questions in AR Experiment

	Conventional Supermarket	Supermarket with virtual atmosphere
Virtual atmospheric elements		Do you think the virtual objects are attractive? Do you think animations of the virtual objects are attractive? Do you think interaction of the virtual objects are attractive? Do you think the music is attractive?
Emotional feeling	Please choose your feeling (- mark imply the 7-scale degree) Unhappy - - - - - - - Happy Annoyed- - - - - - - Pleased Unsatisfied- - - - - - - Satisfied Despairing- - - - - - - Hopeful Bored- - - - - - - Relaxed Melancholic- - - - - - - Contented Sluggish- - - - - - - Frenzied Dull- - - - - - - Jittery Unaroused- - - - - - - Aroused Relaxed- - - - - - - Arousal Calm- - - - - - - Excited Sleepy- - - - - - - Wideawake	
Shopping intention	Do you think the products are attractive? (Product attractiveness) Do you want to explore more in the store? (Instore explore intention) Do you want to come to this store in the future? (Patronage intention) Are you willing to share the store to your friends? (Share intention)	
Opinion on VR		Are you satisfied with these experiences? Do you expect more virtual scenes' adoption in the store? Are you satisfied with the AR application? Do you have higher expectation on AR technology?

Subjective questions	If you have any comments on AR technology, please let me know.

5.5. Experiment process

The second experiment comprised of 4 parts: 1) conventional convenient store without HoloLens2; 2) Candy Park theme with HoloLens 2; 3) Christmas festival theme with HoloLens 2; 4) chaos park theme with HoloLens2. Subjects were asked to experience each of the scene in less than 5 minutes one by one (Figure 5.17), and answer the questionnaire respectively. When experiencing in the store, interaction function was not reminded inside the system, so I had told them to which kinds of elements were interactable.

Figure 5.17 AR Experiment Process

5.6. Experiment result

5.6.1. Descriptive analysis

Figure 5.18 shows 11 subjects attend the experiment, 5 are males and 6 are females.

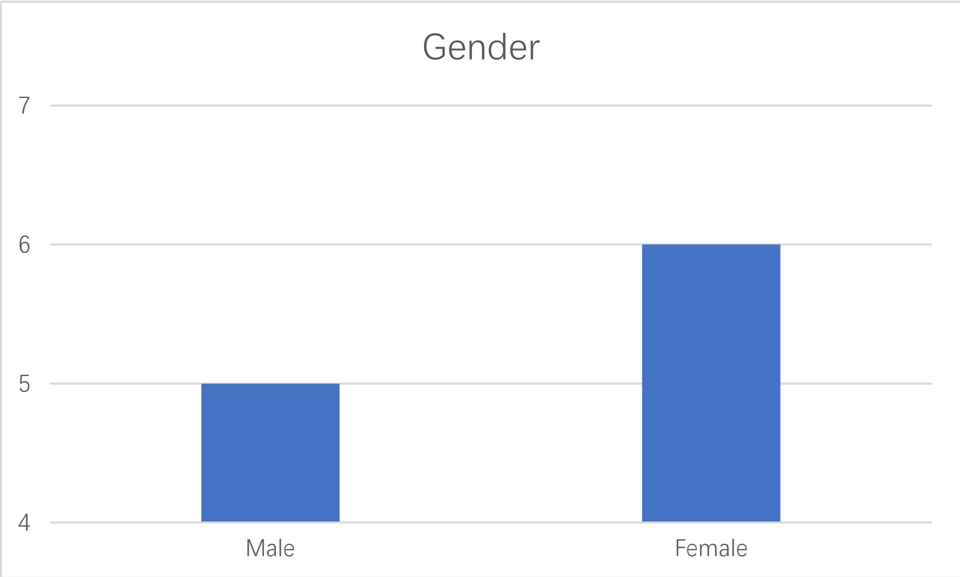

Figure 5.18 Gender Data

Figure 5.19 shows 10 subjects are in 20s, 1 in 40s. people in this age tend to be more interested in new technology compared with other ages.

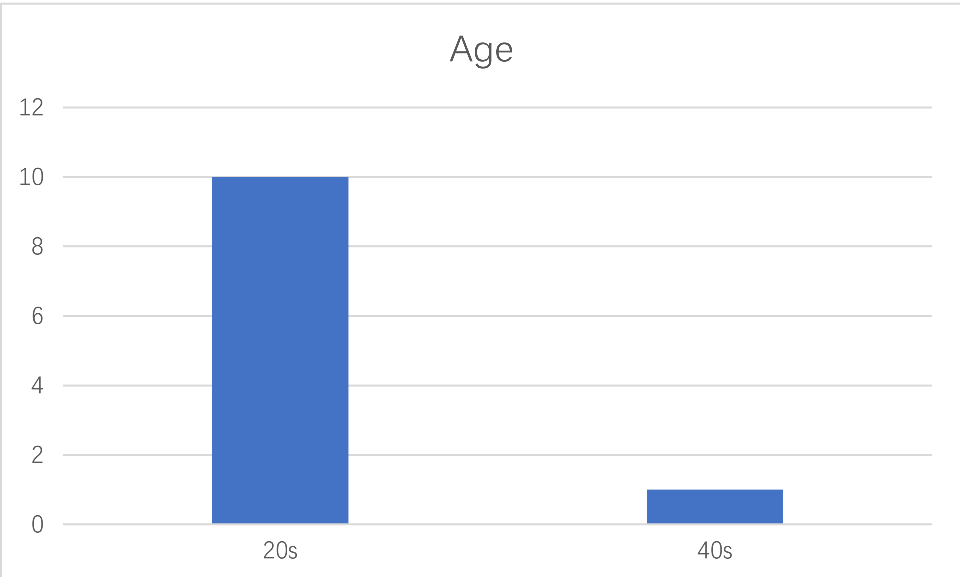

Figure 5.19 Age Data

We first visualize subjects' four atmosphere's emotion in Figure 5.20. Emotion description words in

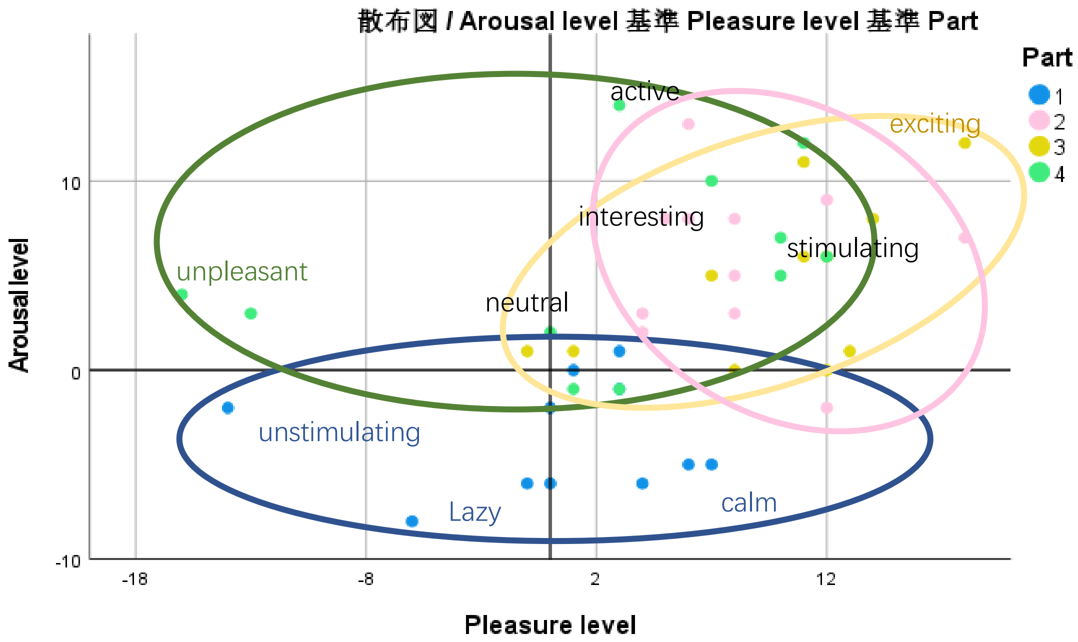

Figure 5.20 Emotional States in four atmospheres

the figures are precise emotion states according to M-R atmospheric emotion states. Different color rings refer to each four time's emotion state, part 1 and part 4 shows more diverse states compared to part 2 and part 3.

In part 1: conventional convenient store, subjects tend to be neutral, calm, lazy and unstimulating states. As a control group, these results explained that conventional store cannot awaken arousal level. In part 2 and part 3, subjects are tending to be more interested, active, excited and stimulating. In part 4, because of chaos design, few subjects show their unpleasant mood compared to other part.

Figure 5.21 show average value of emotion and shopping intention of four experiments. Clearly, almost all the indicators in AR environment have a higher value than conventional environment. Unfortunately, subjects had negative feeling of attractiveness of products, willingness of explore in the store and intention to shar to others. Only intention to come again have positive feedback.

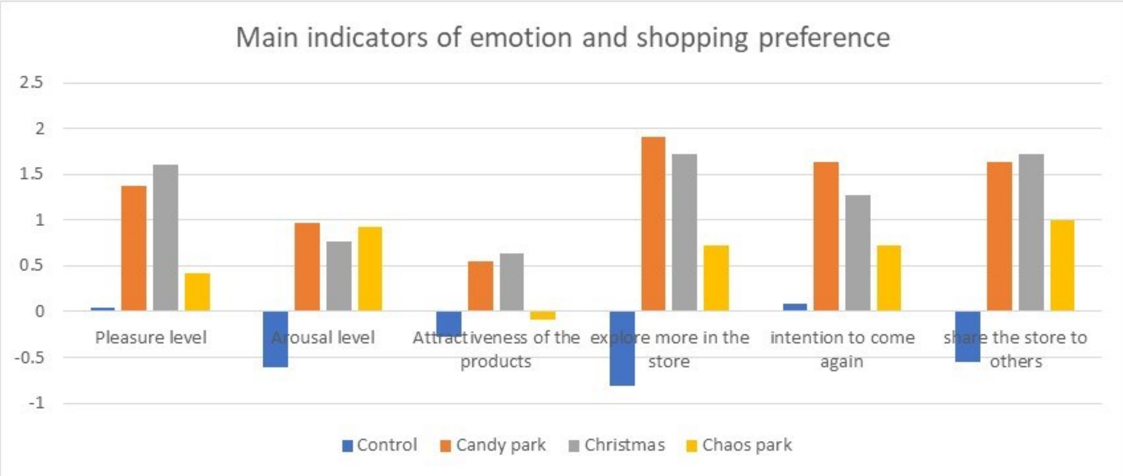

Figure 5.21 Average Value of Emotion and Shopping Intention of Four Experiments

Opinion toward attractiveness of virtual atmospheric elements. In these three cases, subjects show positive attitude toward it.

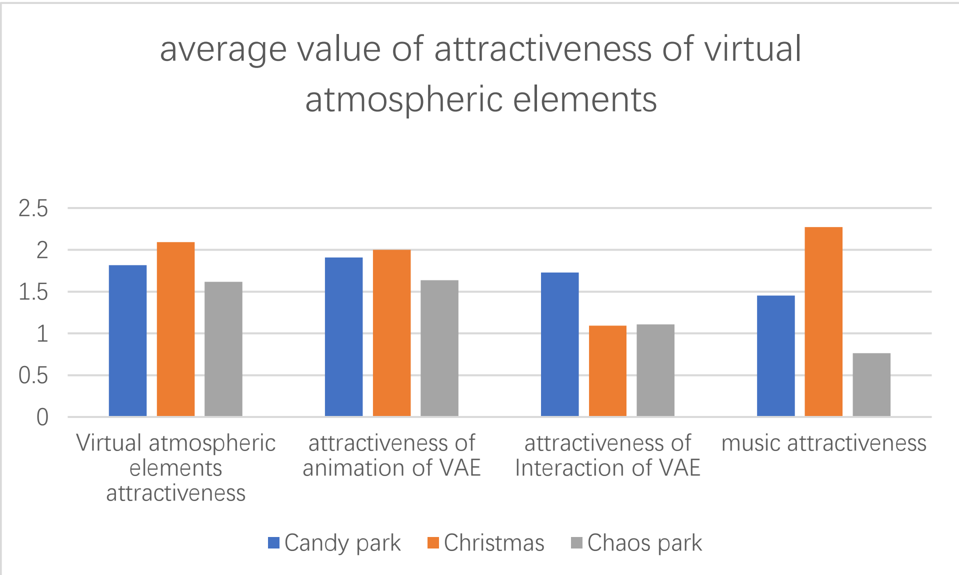

Figure 5.22 Average Value of Attractiveness of Virtual Atmospheric Elements

5.6.2. Comparative analysis

In the first step, I am first to compare if emotional feelings in AR environment vary from conventional environments, ANOVA was conducted. As we can see from above that individuals difference exists, subject factor was also added as dependence. Result in Table. 5.2 reveals pleasure level and arousal level in all four atmospheres are regards as significant different under 95% and 99% respectively. **H1: Compared to conventional supermarkets, all virtual atmospheric elements can contribute to**

emotional change is supported. Tukey's Honest Significant Difference test were also conducted in Table. 5.3 , result shows that pleasure level in Controlled group and Chaos Park doesn't have significant difference, Candy Park and Christmas doesn't have significant different, but they are divided into two groups. Table. 5.4 reveals the controlled group itself have significant difference with all candy park, Christmas and Chaos park. **H2-2: Multiple virtual atmospheres can provide different positive emotional feelings is supported.**

Table. 5.2 ANOVA of Emotional Feelings

Analysis of Variance					
Source		Type III Sum of Squares	Mean Square	F	Sig.
Atmosphere	Pleasure level	2.168	0.723	5.341	0.005
	Arousal level	1.907	0.636	12.355	<0.001

Table. 5.3 Tukey's Honest Significant Difference Test of Pleasure Level

Pleasure level			
Tukey HSD[a]			
Atmosphere	Subset for alpha = 0.1		
	1	2	3
Controlled	0.27		
Chaos Park	2.55	2.55	
Candy Park		8.27	8.27
Christmas	11		9.64
Sig.	0.849	0.190	0.962

Table. 5.4 Tukey's Honest Significant Difference Test of Arousal Level

Arousal level		
Tukey HSD[a]		
Atmosphere	Subset for alpha = 0.1	
	1	2
Controlled	-3.64	
Candy Park		4.64
Christmas		5.55
Chaos Park		5.82
Sig.	1.000	0.909

Next, I conducted Correlation analysis among virtual atmospheric elements and emotions, to figure out what related to emotional feeling. Result in Table. 5.5 reveals virtual object appearance ($p<0.01$), animation of virtual objects ($p<0.01$) and interaction of virtual objects ($p<0.01$) have positive correlation with pleasure level. However, these virtual atmospheric elements were found no correlation with arousal level. **H2: Compared to conventional supermarkets, the exciting virtual atmosphere can result in certain kind of pleasure feeling in brick-and-mortar convenient store is partly supported**

Table. 5.5 Correlation Analysis Among Virtual Atmospheric Elements and Emotions

Correlations					
		Virtual objects appearance	animation of Virtual objects	Interaction of Virtual objects	music attractiveness
Pleasure level	Pearson Correlation	.794**	.787**	.687**	0.350
	Sig.	<0.001	<0.001	<0.001	0.053
Arousal level	Pearson Correlation	-0.035	-0.007	-0.030	-0.077
	Sig.	0.850	0.969	0.874	0.680

Next, correlation of Emotional and Shopping Preference Indicators between 4 Atmospheres was conducted in Table. 5.6 , results show pleasure level have positive correlation with explore intention ($p<0.01$), patronage intention($p<0.01$), willingness to share ($p<0.01$), arousal level have positive correlation with explore intention ($p<0.01$), patronage intention($p<0.05$), willingness to share ($p<0.01$).

Table. 5.6 Correlation of Emotional and Shopping Preference Indicators between 4 Atmospheres

		explore more in the store	intention to come again	share the store to others
Pleasure level	Pearson Correlation	.611**	.563**	.419**
	Sig.	0.000	0.000	0.005
Arousal level	Pearson Correlation	.523**	.327*	.480**
	Sig.	0.000	0.030	0.001

Analysis of Variance (ANOVA) of pleasure level and shopping preference indicators among 4 atmospheres were conducted and the results was show in Table. 5.7. Pleasure level can significantly result in explore intention ($p<0.01$), patronage intention($p<0.01$).

Table. 5.7 ANOVA of Pleasure level and Shopping Preference Indicators between 4 Atmospheres

Analysis of Variance					
Source		Type III Sum of Squares	Mean Square	F	Sig.
Pleasure level	explore more in the store	110.548	6.142	3.346	0.003**
	intention to come again	69.995	3.889	3.156	0.004**
	share the store	71.826	3.990	1.423	0.204

Analysis of Variance (ANOVA) of arousal level and shopping preference indicators among 4 atmospheres were conducted and the results was show in Table. 5.8. Arousal level can significantly result in explore intention ($p<0.01$), patronage intention($p<0.01$).

Table. 5.8 of ANOVA of Arousal Level and Shopping Preference Indicators between 4 Atmospheres

Analysis of Variance					
Source		Type III Sum of Squares	Mean Square	F	Sig.
Arousal level	explore more in the store	103.932	5.470	2.501	0.018**
	intention to come again	66.295	3.489	2.427	0.021**
	share the store	78.159	4.114	1.549	0.155

H3-2: Pleasure emotion have positive impact on patronage intention and H3-3: Pleasure emotion have positive impact on willingness to explore are supported. H3-1: Pleasure emotion have positive impact on attractiveness of products and H3-4: Pleasure emotion have positive impact on willingness to share the store to friends are not supported.

5.6.3. Imperial analysis

I investigated user's opinions toward technologies, 9 out of 11 subjects shows their satisfaction toward the overall prototype atmosphere system in brick-and-mortar convenient store. One subject expressed his neutral opinion on the system: convenient store should be a place for convenient shopping place, more attention was put on target products instead of atmosphere inside the store. Other subject expressed his negative opinion toward the system: in the Christmas atmosphere, connection between atmosphere and products were insufficient, making the atmosphere isolated from the actual shopping utility. 10 out of 11 subjects answered their expectation on more virtual atmosphere applied in brick-and-mortar convenient store. All 11 subjects felt satisfied with the application itself, indicating that although the overall atmospheres are not perfect enough for shopping, the application itself, as a prototype, is satisfied, or at least sufficient in the current technology background. After all the experiments, for all subjects, they all showed their expectation on AR technology, demonstrating subjects had positive opinion on the new technology application.

Besides, subjects' personal subjective opinions are collected in the questionnaire. 8 out of 11 subjects mentioned "interesting" or "funny", "immersive" in their comment, indicating the hedonic feeling can be strongly perceptive by customers, the atmosphere system does impact their emotional feeling. I am surprised to find although the head-mount display was not common for subjects, compared to VR experiment, nobody mentioned the uncomfortableness of wearing such a device, so the device itself is acceptable for users.

6. Conclusion and Discussion

In the thesis, we found virtual atmosphere an important role to impact customers emotional feeling: pleasure and arousal. The emotional feeling then future impact shipping intention, especially hedonic shopping experience and patronage intention. Real atmosphere has been researched for quite a long time, but virtual atmosphere's impact on shopping intention is need to be researched. I step by step verify the atmosphere influence on shopping intention by two experiments: first in VR environment, an undersea atmosphere supermarket, which made it possible to shop in an unbreathable scene, was developed and bring happy and relaxed emotional feeling to customers, further impact on preference toward supermarket, willingness to recommend to friends, patronage intention and future purchase intention. Second, I developed 3 different atmospheres (candy park, Christmas, chaos park) in brick-and-mortar convenient store, to provide interesting and exited shopping experiences in daily life for customers with different preference with the use of HoloLens 2 – an AR glasses. By adopting Mehrabian and Russel atmospheric model, I also verified the multiple virtual atmospheres can impact customer's emotional feeling, and therefore influence user's explore intention and patronage intention.

This research shed a light on possibility of virtual atmospheres for customers in brick-and-mortar. With the help of area recognition capability and see-through display capability, The AR technology itself can currently satisfied the need of bringing interesting atmosphere. However how to commercialize the idea is to be verify in the future.

7. Limitation and future research

7.1. System limitation

There are several design limitations in the system: 1) device's optical limitation, 2) limited numbers of scenes design system 3) realistic commercialize limitation.

HoloLens 2, being one of the most advanced AR devices in current day, there are still disadvantages: the field of view in glasses is limited, only covering part of the view, customers need to move their head around to see the whole atmosphere, especially when checking products, limited field of view led to limited atmosphere, which weaken the immersive experience. The brightness of the device is also a limitation. Detailed atmospheric elements cannot be clearly shown in the display part as in VR environment, so that the exciting atmosphere designed was being limited to certain kinds of scenes which have low requirement on lighting.

In AR experiment, only three atmospheres were designed. While real atmosphere can only have one atmosphere at the same time, multiple virtual atmospheres can exist to satisfy different customer's personal preference. Just like Christmas atmosphere, is not common all over the world, so that weaken the experience. More atmosphere can be designed to awake different kinds of emotional feeling, like horrible scene, crazy scene, the mystery universe scene or so.

Final and most importantly, the prototype itself can satisfy customers' use, but currently unable to commercially adopted. The prototype system cannot define who developed and provide software service, and cannot define who provide devices. The device itself is not economic enough and compact enough, so the experiment is only designed here to provide possibility of interface.

7.2. Research Limitation

There are several research limitations: 1) subject limitation, 2) emotional limitation, 3) shopping intention evaluation limitations, 4) commercialize possibility.

In these experiments, due to limitation of time and permission of brick-and-mortar convenient store, less than 20 subjects respectively attended the experiment. Every subject sample can impact greatly in the results. The experiments were conducted in Japan, especially in certain area of Tokyo, and not covering people of different ages. More subjects should be invited to the experiment.

Emotional feeling, an important part. But in this AR experiment, only three atmospheres were conducted, main emotions awakened were happy, pleasure, interesting. It more emotion can be developed, how virtual atmospheres results in different emotional feeling and thus result in different shopping intention can be discovered.

Shopping intention, covering a wide range of intention and behaviors, in the thesis, only four intentions were chosen to evaluated. Brick-and-mortar supermarkets and convenient store play important role in daily purchase and life, the internal connection can be further being discovered.

8. Acknowledgement

2021 to 2023 is a difficult period for all the people in the world. Fortunately, in the time I met professor Tetsuro Ogi, and Keio SDM. I have to say it is a memorable period for my whole life, in the Master 2 years period, I spent one year outside Japan, and one year in Japan. Even though all the classes and research in the year were outside Japan, professor Ogi was quite patient to me, giving me critical implication in my research life. After I arrived in Japan in the second year, I can quickly work on my research and got two chances to present in scholar society. It is a cherish experience and it enriched my life. If it is not for Professor Ogi, I cannot study and work on VR/VR field, which is one of my favorite fields. Of course, Professor also helped me a lot in my research thesis, providing me unnecessary guidance, pushing me forward to be a better researcher.

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Of course, I appreciated for my parents, it is their mental and economic support that help me achieve my dream to study abroad. It is interesting that they gave me my Chinese name, including meaning of studying and forwarding the world. Although we are now living in different country, but they do really give me courage, and I can also contact with parents, sharing my life in Japan and so.

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10. Appendix

10.1. System coding: Camera Moving Script in VR experiment

```
using System;

using System.Collections.Generic;

using System.Linq;

using System.Text;

using UnityEngine;


public class FreeCamera : MonoBehaviour

{

    public float movementSpeed = 10f;

    public float fastMovementSpeed = 100f;

    public float freeLookSensitivity = 3f;

    public float zoomSensitivity = 10f;

    public float fastZoomSensitivity = 50f;

    private bool looking = false;


    void Update()

    {

        var fastMode = Input.GetKey(KeyCode.LeftShift) ||
Input.GetKey(KeyCode.RightShift);

        var movementSpeed = fastMode ? this.fastMovementSpeed : this.movementSpeed;


        if (Input.GetKey(KeyCode.A) || Input.GetKey(KeyCode.LeftArrow))

        {

            transform.position = transform.position + (-transform.right * movementSpeed *
```

```
Time.deltaTime);
        }

        if (Input.GetKey(KeyCode.D) || Input.GetKey(KeyCode.RightArrow))
        {
            transform.position = transform.position + (transform.right * movementSpeed *
Time.deltaTime);
        }

        if (Input.GetKey(KeyCode.W) || Input.GetKey(KeyCode.UpArrow))
        {
            transform.position = transform.position + (transform.forward * movementSpeed
* Time.deltaTime);
        }

        if (Input.GetKey(KeyCode.S) || Input.GetKey(KeyCode.DownArrow))
        {
            transform.position = transform.position + (-transform.forward * movementSpeed
* Time.deltaTime);
        }

        if (Input.GetKey(KeyCode.Q))
        {
            transform.position = transform.position + (transform.up * movementSpeed *
Time.deltaTime);
        }

        if (Input.GetKey(KeyCode.E))
        {
```

```
            transform.position = transform.position + (-transform.up * movementSpeed * Time.deltaTime);
        }

        if (Input.GetKey(KeyCode.R) || Input.GetKey(KeyCode.PageUp))
        {
            transform.position = transform.position + (Vector3.up * movementSpeed * Time.deltaTime);
        }

        if (Input.GetKey(KeyCode.F) || Input.GetKey(KeyCode.PageDown))
        {
            transform.position = transform.position + (-Vector3.up * movementSpeed * Time.deltaTime);
        }

        if (looking)
        {
            float newRotationX = transform.localEulerAngles.y + Input.GetAxis("Mouse X") * freeLookSensitivity;
            float newRotationY = transform.localEulerAngles.x - Input.GetAxis("Mouse Y") * freeLookSensitivity;
            transform.localEulerAngles = new Vector3(newRotationY, newRotationX, 0f);
        }

        float axis = Input.GetAxis("Mouse ScrollWheel");
        if (axis > 0)
        {
            GetComponent<Camera>().fieldOfView--;
```

```
        }
        else if (axis < 0)
        {
            GetComponent<Camera>().fieldOfView++;
        }

        if (Input.GetKeyDown(KeyCode.Mouse1))
        {
            StartLooking();
        }
        else if (Input.GetKeyUp(KeyCode.Mouse1))
        {
            StopLooking();
        }
    }

    void OnDisable()
    {
        StopLooking();
    }
    public void StartLooking()
    {
        looking = true;
        Cursor.visible = false;
        Cursor.lockState = CursorLockMode.Locked;
    }
    public void StopLooking()
    {
        looking = false;
```

```
        Cursor.visible = true;

        Cursor.lockState = CursorLockMode.None;

    }

}
```

10.2. System coding: Gigger animation in AR experiment

```
using System.Collections;

using System.Collections.Generic;

using UnityEngine;


public class Jiggler : MonoBehaviour

{

    [Range(0, 1)]

    public float power = .1f;


    [Header("Position Jiggler")]

    public bool jigPosition = true;

    public Vector3 positionJigAmount;

    [Range(0, 120)]

    public float positionFrequency = 10;

    float positionTime;


    [Header("Rotation Jiggler")]

    public bool jigRotation = true;

    public Vector3 rotationJigAmount;

    [Range(0, 120)]

    public float rotationFrequency = 10;
```

```
float rotationTime;


[Header("Scale Jiggler")]

public bool jigScale = true;

public Vector3 scaleJigAmount = new Vector3(.1f, -.1f, .1f);

[Range(0, 120)]

public float scaleFrequency = 10;

float scaleTime;


Vector3 basePosition;

Quaternion baseRotation;

Vector3 baseScale;


void Start(){

    basePosition = this.transform.localPosition;

    baseRotation = this.transform.localRotation;

    baseScale = this.transform.localScale;

}


// Update is called once per frame

void Update()

{

    var dt = Time.deltaTime;

    positionTime += dt * positionFrequency;

    rotationTime += dt * rotationFrequency;

    scaleTime += dt * scaleFrequency;


    if (jigPosition)

        transform.localPosition = basePosition + positionJigAmount *
```

```
Mathf.Sin(positionTime) * power;
        if (jigRotation)
            transform.localRotation = baseRotation * Quaternion.Euler(rotationJigAmount *
Mathf.Sin(rotationTime) * power);
        if (jigScale)
            transform.localScale = baseScale + scaleJigAmount * Mathf.Sin(scaleTime) *
power;
    }
}
```

10.3. System coding: Near Interaction Grabbable for AR interaction by Microsoft

```
// Copyright (c) Microsoft Corporation.
// Licensed under the MIT License.

using UnityEngine;

namespace Microsoft.MixedReality.Toolkit.Input
{
    /// <summary>
    /// Add a NearInteractionGrabbable component to any GameObject that has a collidable
    /// on it in order to make that collidable near grabbable.
    ///
    /// Any IMixedRealityNearPointer will then dispatch pointer events
    /// to the closest near grabbable objects.
    ///
    /// Additionally, the near pointer will send focus enter and exit events when the
    /// decorated object is the closest object to the near pointer
```

```
    /// </summary>
    [AddComponentMenu("Scripts/MRTK/Services/NearInteractionGrabbable")]
    public class NearInteractionGrabbable : MonoBehaviour
    {
        [Tooltip("Check to show a tether from the position where object was grabbed to
the hand when manipulating. Useful for things like bounding boxes where resizing/rotating
might be constrained.")]
        public bool ShowTetherWhenManipulating = false;

        [Tooltip("Used to designate this interaction grabbable as a bounds handle")]
        public bool IsBoundsHandles = false;

        void OnEnable()
        {
            // As of https://docs.unity3d.com/ScriptReference/Physics.ClosestPoint.html
            // ClosestPoint call will only work on specific types of colliders.
            // Using incorrect type of collider will emit warning from FocusProvider,
            // but grab behavior will be broken at this point.
            // Emit exception on initialization, when we know grab interaction is used
            // on this object to make an error clearly visible.

            // Note that there can be multiple colliders on an object - as long as one
            // of them are of the valid type, this object will work with
NearInteractionGrabbable
            Collider[] colliders = gameObject.GetComponents<Collider>();
            bool containsValidCollider = false;
            for (int i = 0; i < colliders.Length && !containsValidCollider; i++)
            {
                Collider collider = colliders[i];
```

```
                containsValidCollider =
                    (collider is BoxCollider) ||
                    (collider is CapsuleCollider) ||
                    (collider is SphereCollider) ||
                    (collider is MeshCollider && (collider as MeshCollider).convex);
            }

            if (!containsValidCollider)
            {
                Debug.LogError("NearInteractionGrabbable requires a " +
                    "BoxCollider, SphereCollider, CapsuleCollider or a convex
MeshCollider on an object. " +
                    "Otherwise grab interaction will not work correctly.");
            }
        }
    }
}
```

10.4.33 System coding: Object Manipulation in AR experiment by Microsoft

```
using Microsoft.MixedReality.Toolkit.Experimental.Physics;
using Microsoft.MixedReality.Toolkit.Input;
using Microsoft.MixedReality.Toolkit.Physics;
using Microsoft.MixedReality.Toolkit.Utilities;
using System;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.Assertions;
using UnityEngine.Serialization;

namespace Microsoft.MixedReality.Toolkit.UI
```

```
{
    /// <summary>
    /// This script allows for an object to be movable, scalable, and rotatable with one or two hands.
    /// You may also configure the script on only enable certain manipulations. The script works with
    /// both HoloLens' gesture input and immersive headset's motion controller input.
    /// </summary>
    [HelpURL("https://docs.microsoft.com/windows/mixed-reality/mrtk-unity/features/ux-building-blocks/object-manipulator")]
    [RequireComponent(typeof(ConstraintManager))]
    public class ObjectManipulator : MonoBehaviour, IMixedRealityPointerHandler, IMixedRealityFocusChangedHandler, IMixedRealitySourcePoseHandler
    {
#region Public Enums

        /// <summary>
        /// Describes what pivot the manipulated object will rotate about when
        /// you rotate your hand. This is not a description of any limits or
        /// additional rotation logic. If no other factors (such as constraints)
        /// are involved, rotating your hand by an amount should rotate the object
        /// by the same amount.
        /// For example a possible future value here is RotateAboutUserDefinedPoint
        /// where the user could specify a pivot that the object is to rotate
        /// around.
        /// An example of a value that should not be found here is MaintainRotationToUser
        /// as this restricts rotation of the object when we rotate the hand.
        /// </summary>
        public enum RotateInOneHandType
        {
            RotateAboutObjectCenter,
            RotateAboutGrabPoint
        }

        [Flags]
        public enum ReleaseBehaviorType
        {
            KeepVelocity = 1 << 0,
            KeepAngularVelocity = 1 << 1
        }

        #endregion Public Enums
```

```
#region Serialized Fields

        [SerializeField]
        [Tooltip("Transform that will be dragged. Defaults to the object of the component.")]
        private Transform hostTransform = null;

        /// <summary>
        /// Transform that will be dragged. Defaults to the object of the component.
        /// </summary>
        public Transform HostTransform
        {
            get
            {
                if (hostTransform == null)
                {
                    hostTransform = gameObject.transform;
                }

                return hostTransform;
            }
            set => hostTransform = value;
        }

        [SerializeField]
        [EnumFlags]
        [Tooltip("Can manipulation be done only with one hand, only with two hands, or with
both?")]
        private ManipulationHandFlags manipulationType = ManipulationHandFlags.OneHanded |
ManipulationHandFlags.TwoHanded;
```

```
/// <summary>
/// Can manipulation be done only with one hand, only with two hands, or with both?
/// </summary>
public ManipulationHandFlags ManipulationType
{
    get => manipulationType;
    set => manipulationType = value;
}

[SerializeField]
[EnumFlags]
[Tooltip("What manipulation will two hands perform?")]
private TransformFlags twoHandedManipulationType = TransformFlags.Move | TransformFlags.Rotate | TransformFlags.Scale;

/// <summary>
/// What manipulation will two hands perform?
/// </summary>
public TransformFlags TwoHandedManipulationType
{
    get => twoHandedManipulationType;
    set => twoHandedManipulationType = value;
}

[SerializeField]
[Tooltip("Specifies whether manipulation can be done using far interaction with pointers.")]
private bool allowFarManipulation = true;
```

```
/// <summary>
/// Specifies whether manipulation can be done using far interaction with pointers.
/// </summary>
public bool AllowFarManipulation
{
    get => allowFarManipulation;
    set => allowFarManipulation = value;
}

[SerializeField]
[Tooltip(
    "Whether physics forces are used to move the object when performing near manipulations. " +
    "Off will make the object feel more directly connected to the hand. On will honor the mass and inertia of the object. " +
    "The default is off.")]
private bool useForcesForNearManipulation = false;

/// <summary>
/// Whether physics forces are used to move the object when performing near manipulations.
/// </summary>
/// <remarks>
/// <para>Setting this to <c>false</c> will make the object feel more directly connected to the
/// users hand. Setting this to <c>true</c> will honor the mass and inertia of the object,
/// but may feel as though the object is connected through a spring. The default is <c>false</c>.</para>
/// </remarks>
public bool UseForcesForNearManipulation
```

```
{
    get => useForcesForNearManipulation;
    set => useForcesForNearManipulation = value;
}

[SerializeField]
[Tooltip("Rotation behavior of object when using one hand near")]
private RotateInOneHandType oneHandRotationModeNear = RotateInOneHandType.RotateAboutGrabPoint;

/// <summary>
/// Rotation behavior of object when using one hand near
/// </summary>
public RotateInOneHandType OneHandRotationModeNear
{
    get => oneHandRotationModeNear;
    set => oneHandRotationModeNear = value;
}

[SerializeField]
[Tooltip("Rotation behavior of object when using one hand at distance")]
private RotateInOneHandType oneHandRotationModeFar = RotateInOneHandType.RotateAboutGrabPoint;

/// <summary>
/// Rotation behavior of object when using one hand at distance
/// </summary>
public RotateInOneHandType OneHandRotationModeFar
{
```

```
        get => oneHandRotationModeFar;
        set => oneHandRotationModeFar = value;
    }

    [SerializeField]
    [EnumFlags]
    [Tooltip("Rigid body behavior of the dragged object when releasing it.")]
    private ReleaseBehaviorType releaseBehavior = ReleaseBehaviorType.KeepVelocity | ReleaseBehaviorType.KeepAngularVelocity;

    /// <summary>
    /// Rigid body behavior of the dragged object when releasing it.
    /// </summary>
    public ReleaseBehaviorType ReleaseBehavior
    {
        get => releaseBehavior;
        set => releaseBehavior = value;
    }

    /// <summary>
    /// Obsolete: Whether to enable frame-rate independent smoothing.
    /// </summary>
    [Obsolete("SmoothingActive is obsolete and will be removed in a future version. Applications should use SmoothingFar, SmoothingNear or a combination of the two.")]
    public bool SmoothingActive
    {
        get => smoothingFar;
        set => smoothingFar = value;
    }
```

```
[SerializeField]
[Tooltip("The concrete type of TransformSmoothingLogic to use for smoothing between transforms.")]
[Implements(typeof(ITransformSmoothingLogic), TypeGrouping.ByNamespaceFlat)]
private SystemType transformSmoothingLogicType = typeof(DefaultTransformSmoothingLogic);

[FormerlySerializedAs("smoothingActive")]
[SerializeField]
[Tooltip("Frame-rate independent smoothing for far interactions. Far smoothing is enabled by default.")]
private bool smoothingFar = true;

/// <summary>
/// Whether to enable frame-rate independent smoothing for far interactions.
/// </summary>
/// <remarks>
/// Far smoothing is enabled by default.
/// </remarks>
public bool SmoothingFar
{
    get => smoothingFar;
    set => smoothingFar = value;
}

[SerializeField]
[Tooltip("Frame-rate independent smoothing for near interactions. Note that enabling near smoothing may be perceived as being 'disconnected' from the hand.")]
```

```
        private bool smoothingNear = true;

        /// <summary>
        /// Whether to enable frame-rate independent smoothing for near interactions.
        /// </summary>
        /// <remarks>
        /// Note that enabling near smoothing may be perceived as being 'disconnected' from the hand.
        /// </remarks>
        public bool SmoothingNear
        {
            get => smoothingNear;
            set => smoothingNear = value;
        }

        [SerializeField]
        [Range(0, 1)]
        [Tooltip("Enter amount representing amount of smoothing to apply to the movement. Smoothing of 0 means no smoothing. Max value means no change to value.")]
        private float moveLerpTime = 0.001f;

        /// <summary>
        /// Enter amount representing amount of smoothing to apply to the movement. Smoothing of 0 means no smoothing. Max value means no change to value.
        /// </summary>
        public float MoveLerpTime
        {
            get => moveLerpTime;
            set => moveLerpTime = value;
```

```
        }

        [SerializeField]
        [Range(0, 1)]
        [Tooltip("Enter amount representing amount of smoothing to apply to the rotation. Smoothing of 0 means no smoothing. Max value means no change to value.")]
        private float rotateLerpTime = 0.001f;

        /// <summary>
        /// Enter amount representing amount of smoothing to apply to the rotation. Smoothing of 0 means no smoothing. Max value means no change to value.
        /// </summary>
        public float RotateLerpTime
        {
            get => rotateLerpTime;
            set => rotateLerpTime = value;
        }

        [SerializeField]
        [Range(0, 1)]
        [Tooltip("Enter amount representing amount of smoothing to apply to the scale. Smoothing of 0 means no smoothing. Max value means no change to value.")]
        private float scaleLerpTime = 0.001f;

        /// <summary>
        /// Enter amount representing amount of smoothing to apply to the scale. Smoothing of 0 means no smoothing. Max value means no change to value.
        /// </summary>
        public float ScaleLerpTime
```

```
{
    get => scaleLerpTime;
    set => scaleLerpTime = value;
}

[SerializeField]
[Tooltip("Enable or disable constraint support of this component. When enabled transform
" +
    "changes will be post processed by the linked constraint manager.")]
private bool enableConstraints = true;
/// <summary>
/// Enable or disable constraint support of this component. When enabled, transform
/// changes will be post processed by the linked constraint manager.
/// </summary>
public bool EnableConstraints
{
    get => enableConstraints;
    set => enableConstraints = value;
}

[SerializeField]
[Tooltip("Constraint manager slot to enable constraints when manipulating the object.")]
private ConstraintManager constraintsManager;
/// <summary>
/// Constraint manager slot to enable constraints when manipulating the object.
/// </summary>
public ConstraintManager ConstraintsManager
{
    get => constraintsManager;
```

```
        set => constraintsManager = value;
    }

    [SerializeField]
    [Tooltip("Elastics Manager slot to enable elastics simulation when manipulating the object.")]
    private ElasticsManager elasticsManager;
    /// <summary>
    /// Elastics Manager slot to enable elastics simulation when manipulating the object.
    /// </summary>
    public ElasticsManager ElasticsManager
    {
        get => elasticsManager;
        set => elasticsManager = value;
    }

    #endregion Serialized Fields

#region Event handlers
    [Header("Manipulation Events")]
    [SerializeField]
    [FormerlySerializedAs("OnManipulationStarted")]
    private ManipulationEvent onManipulationStarted = new ManipulationEvent();

    /// <summary>
    /// Unity event raised on manipulation started
    /// </summary>
    public ManipulationEvent OnManipulationStarted
    {
```

```
    get => onManipulationStarted;
    set => onManipulationStarted = value;
}

[SerializeField]
[FormerlySerializedAs("OnManipulationEnded")]
private ManipulationEvent onManipulationEnded = new ManipulationEvent();

/// <summary>
/// Unity event raised on manipulation ended
/// </summary>
public ManipulationEvent OnManipulationEnded
{
    get => onManipulationEnded;
    set => onManipulationEnded = value;
}

[SerializeField]
[FormerlySerializedAs("OnHoverEntered")]
private ManipulationEvent onHoverEntered = new ManipulationEvent();

/// <summary>
/// Unity event raised on hover started
/// </summary>
public ManipulationEvent OnHoverEntered
{
    get => onHoverEntered;
    set => onHoverEntered = value;
}
```

```
        [SerializeField]
        [FormerlySerializedAs("OnHoverExited")]
        private ManipulationEvent onHoverExited = new ManipulationEvent();

        /// <summary>
        /// Unity event raised on hover ended
        /// </summary>
        public ManipulationEvent OnHoverExited
        {
            get => onHoverExited;
            set => onHoverExited = value;
        }

        #endregion Event Handlers

#region Hand Event Handlers

#region MonoBehaviour Functions

        private void Awake()
        {
            moveLogic = new ManipulationMoveLogic();
            rotateLogic = new TwoHandRotateLogic();
            scaleLogic = new TwoHandScaleLogic();
            smoothingLogic = Activator.CreateInstance(transformSmoothingLogicType) as
ITransformSmoothingLogic;

            if (elasticsManager)
            {
                elasticsManager.InitializeElastics(HostTransform);
            }
        }
        protected virtual void Start()
```

```
        {
            rigidBody = HostTransform.GetComponent<Rigidbody>();
            if (constraintsManager == null && EnableConstraints)
            {
                constraintsManager = gameObject.EnsureComponent<ConstraintManager>();
            }

            // Get child objects with NearInteractionGrabbable attached
            var children = GetComponentsInChildren<NearInteractionGrabbable>();

            if (children.Length == 0)
            {
                Debug.Log($"Near interactions are not enabled for {gameObject.name}. To
enable near interactions, add a " +
                    $"{nameof(NearInteractionGrabbable)} component to {gameObject.name}
or to a child object of {gameObject.name} that contains a collider.");
            }
        }

        #endregion

        /// <inheritdoc />

        public virtual void OnPointerDown(MixedRealityPointerEventData eventData)

        {

            if (eventData.used ||

                eventData.Pointer == null ||

                eventData.Pointer.Result == null ||

                (!allowFarManipulation && eventData.Pointer as IMixedRealityNearPointer
== null))

            {

                return;

            }


            // If we only allow one handed manipulations, check there is no hand
interacting yet.

            if (manipulationType != ManipulationHandFlags.OneHanded ||
```

```
pointerDataList.Count == 0)
            {
                if (!TryGetPointerDataWithId(eventData.Pointer.PointerId, out _))
                {
                    pointerDataList.Add(new PointerData(eventData.Pointer,
eventData.Pointer.Result.Details.Point));

                    // Re-initialize elastic systems.
                    if (elasticsManager)
                    {
                        elasticsManager.InitializeElastics(HostTransform);
                    }

                    // Call manipulation started handlers
                    if (IsTwoHandedManipulationEnabled)
                    {
                        if (!isManipulationStarted)
                        {
                            HandleManipulationStarted();
                        }
                        HandleTwoHandManipulationStarted();
                    }
                    else if (IsOneHandedManipulationEnabled)
                    {
                        if (!isManipulationStarted)
                        {
                            HandleManipulationStarted();
                        }
                        HandleOneHandMoveStarted();
```

```
                }
            }
        }

        if (pointerDataList.Count > 0)
        {
            // Always mark the pointer data as used to prevent any other behavior to
handle pointer events
            // as long as the ObjectManipulator is active.
            // This is due to us reacting to both "Select" and "Grip" events.
            eventData.Use();
        }
    }

    bool hasFirstPointerDraggedThisFrame = false;

    public virtual void OnPointerDragged(MixedRealityPointerEventData eventData)
    {
        // Call manipulation updated handlers
        if (IsOneHandedManipulationEnabled)
        {
            HandleOneHandMoveUpdated();
        }
        else if (IsTwoHandedManipulationEnabled)
        {
            if (hasFirstPointerDraggedThisFrame)
            {
                HandleTwoHandManipulationUpdated();
                hasFirstPointerDraggedThisFrame = false;
```

```
                }
                else
                {
                    hasFirstPointerDraggedThisFrame = true;
                }
            }
        }

        /// <inheritdoc />
        public virtual void OnPointerUp(MixedRealityPointerEventData eventData)
        {
            // Get pointer data before they are removed from the map
            Vector3 grabPoint = GetPointersGrabPoint();
            Vector3 velocity = GetPointersVelocity();
            Vector3 angularVelocity = GetPointersAngularVelocity();

            if (TryGetPointerDataWithId(eventData.Pointer.PointerId, out PointerData
pointerDataToRemove))
            {
                pointerDataList.Remove(pointerDataToRemove);
            }

            // Call manipulation ended handlers
            if (manipulationType.IsMaskSet(ManipulationHandFlags.TwoHanded) &&
pointerDataList.Count == 1)
            {
                if (manipulationType.IsMaskSet(ManipulationHandFlags.OneHanded))
                {
                    HandleOneHandMoveStarted();
```

```
            hasFirstPointerDraggedThisFrame = false;
        }
        else
        {
            HandleManipulationEnded(grabPoint, velocity, angularVelocity);
        }
    }
    else if (isManipulationStarted && pointerDataList.Count == 0)
    {
        HandleManipulationEnded(grabPoint, velocity, angularVelocity);
    }

    eventData.Use();
}

#endregion Hand Event Handlers
```