ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

DESIGN AND DEVELOPMENT OF A SPATIAL INTERFACE TOOLKIT USING MIXED REALITY TECHNOLOGIES FOR AUTISTIC PEOPLE WITH SENSORY PROCESSING DISORDER

M.Sc. THESIS

Begüm MORALIOĞLU

Department of Informatics

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

DUYUSAL İŞLEME BOZUKLUĞU OLAN OTİSTİK BİREYLER İÇİN KARMA GERÇEKLİK TEKNOLOJİLERİNİ KULLANAN MEKANSAL ARAYÜZ ARAÇ TAKIMI TASARIMI VE GELİŞTİRİLMESİ

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“You never change things by fighting the existing reality.

To change something, build a new model that makes the existing model obsolete”

Buckminister FULLER

FOREWORD

I grew up in the 90s decade playing video games. Classics such as Duke Nukem, Prince of Persia, Super Mario were my favorites. In those times, I had always dreamed to live inside of my video games. To me, the computer screen was a portal to wander through a world of 2D graphics. However, immersing into a virtual world had not been a possibility until the recent development of artificial reality technologies like augmented, virtual, and mixed reality. Today, we have come to a point where we can harmonize virtual worlds into our real lives. And I feel lucky to have seen this transition and take a little part in the development progress of these technologies.

I want to thank my mother Yeşim MORALIOĞLU for being on my side at all times, giving me her endless love, helping me during all my school life, and of course, assisting me with the pilot study in Bursa.

And my father İrfan MORALIOĞLU for buying me my first computer, leading my way through the computational and technological world.

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And my final words are for people with autism spectrum disorder. You are lovely as you are. It is ok to be a little different.

December 2018 Begüm MORALIOĞLU
(Architect)

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ABBREVIATIONS

2D	: Two-dimensional
3D	: Three-dimensional
App	: Appendix
AR	: Augmented Reality
ASD	: Autism Spectrum Disorder
AV	: Augmented Virtuality
CVLE	: Collaborative Virtual Learning Environment
HMD	: Head-mounted Display
HPU	: Holographic Processing Unit
MR	: Mixed Reality
PC	: Personal Computer
SPD	: Sensory Processing Disorder
UX	: User Experience
VC	: Virtuality Continuum
VPL	: Visual Programming Lab
VR	: Virtual Reality
VW	: Virtual World
XR	: Extended Reality

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DESIGN AND DEVELOPMENT OF A SPATIAL INTERFACE TOOLKIT USING MIXED REALITY TECHNOLOGIES FOR AUTISTIC PEOPLE WITH SENSORY PROCESSING DISORDER

SUMMARY

The Extended Reality (XR) technologies like Mixed Reality (MR) are expanding the physical world with improvements to the real environment. While this expansion affects the daily habits of people, it is also affecting the scope of architecture. As Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality becoming popular and ubiquitous, the content of architectural studies is broadened with extended realities into virtual worlds.

In 1965, Ivan Sutherland mentioned virtual worlds in his research called “The Ultimate Display” by saying “The screen is a window through which one sees a virtual world. The challenge is to make that world look real, act real, sound real, feel real”. Today in 2018, the developed technologies provide many opportunities to engage virtual worlds not just via a screen, also with haptic devices, goggles, projectors and many other. Nevertheless, the question is how it is possible to take advantage of virtual worlds and make the quality of life in the physical world better.

This study explores spatial interface design and development for Mixed Reality, to help autistic people with sensory difficulties by making the spaces customizable and interactive to improve their daily lives. In the scope of the study, along with the various resources on Autism Spectrum Disorder (ASD), and MR technology, existing interface designs of applications for autistic people are examined. After the examination, the results are compared, and the spatial interface design is proposed accordingly. A prototype of the interface is tested on 12 autistic kids between the ages 6-16 to observe their reactions to the HoloLens device. The initial results are shared in this study, and the future of spatial interface design and development for autistic people is discussed further.

In the end, an open-source spatial interface toolkit named “My Ho Me” is proposed to be implemented into the MR applications that assist autistic people with sensory difficulties.

DUYUSAL İŞLEME BOZUKLUĞU OLAN OTİSTİK BİREYLER İÇİN KARMA GERÇEKLİK TEKNOLOJİLERİNİ KULLANAN MEKANSAL ARAYÜZ ARAÇ TAKIMI TASARIMI VE GELİŞTİRİLMESİ

ÖZET

Karma Gerçeklik teknolojisinin de dahil olduğu tüm Genişletilmiş Gerçeklik teknolojileri, fiziksel dünyayı sanal eklentilerle geliştirerek sınırlarını genişletmektedir. Bu teknolojiler, her gün kullanılan cihazlarda mümkün kılınarak insanların günlük alışkanlıklarını etkilerken, mimarlık biliminin kapsamını da değiştirmektedir. Bu yüzden Sanal Gerçeklik, Artırılmış Gerçeklik ve Karma Gerçeklik teknolojilerinin popülerleşmesi ve yaygınlaşmasıyla, mimari çalışmaların içeriği, genişletilmiş gerçekliklerle sanal dünyalara doğru uzanmıştır.

Ivan Sutherland, 1965 yılında yayınladığı "The Ultimate Display" adlı çalışmasında sanal dünyaları şu şekilde tanımlamaktadır: "Bilgisayar ekranı sanal dünyaya açılan bir penceredir. Asıl zorluk bu sanal dünyayı görüntüsü ile, davranışlarıyla, sesiyle, ve hissiyati ile gerçekçi tasarlamaktır." Bugün 2018 yılında gelişmiş teknolojiler, sanal dünyalar ile etkileşim kurmamızı sadece ekranlar aracılığı ile sağlamamaktadır. Ekran dışında dokunmatik aletler, gözlükler, projektörler gibi çeşitli seçenekler de bulunmaktadir. Asıl soru bu sanal dünyalardan faydalanarak fiziksel dünyamızdaki yaşamın kalitesini nasıl artıracağımızdır.

Bu çalışma, karma gerçeklik teknolojisi ile mekansal arayüz tasarım ve geliştirmesini ele almaktadır. Bu arayüz sayesinde otizm spektrum bozukluğu olan insanların içinde bulundukları ortamları kişiselleştirmeleri ve bu mekanlarla etkileşim kurabilmeleri amaçlanmakta ve böylelikle günlük yaşamlarını iyileştirmeleri hedeflenmektedir. Çalışma altı bölümden oluşmaktadır. Bunlar; giriş, arka plan çalışmaları, yöntem, elde edilen sonuçlar, tartışma, sonuç ve gelecek çalışmalar bölümleridir.

Giriş bölümünde çalışmanın amacı, hedefi ve yöntemi belirtilmiştir. Buna göre çalışmanın amacı; duyusal işleme bozukluğu olan otistiklerin çevrelerindeki değişikliklerden en az şekilde etkilenmelerini sağlayacak, mekanlara hızlıca müdahale edebilecek bir araç araştırılmasıdır. Çalışmanın hedefi, kapsam doğrultusunda duyusal işleme bozukluğu olan otistiklere yardımcı olabilecek karma gerçeklik teknolojilerini kullanan bir mekansal arayüz araç takımı tasarımı ve geliştirilmesidir. Çalışmanın yöntemi olarak da aksiyon araştırma modeli çalışmaya göre adapte edilmiştir. Aksiyon araştırma modeline göre duyusal işleme bozukluğu olan otistiklere yardımcı teknolojilerdeki eksikler ve problemler belirlenmiş ve otistiklerin günlük yaşantılarını geliştirmeye yardımcı olabilecek çözümler bulmak üzere harekete geçilmiştir. Bu yöntemin hedefi otistiklere ve benzer topluluklara yardımcı olabilecek son teknolojiler hakkında bilgi paylaşmını gerçekleştirmektir.

Arka plan çalışmaları kapsamında otizm spektrum rahatsızlığının genel özellikleri hakkında bilgi toplanmış, çalışmaya katkıda bulunabilecek güçlü ve zayıf tarafları araştırılmıştır. Bu araştırmalar sonucunda otistiklerin teknolojik cihazlara olan yatkınlığı belirlenmiştir. Bunun yanında görsel algı ve iletişim becerilerinin yüksek olduğu, bu yüzden otistiklere yardımcı teknolojik uygulamalarda görsellere ağırlık

verildiği bilgisine ulaşılmıştır. Genel bilgilerin dışında otizm spektrum rahatsızlığına yönelik artırılmış, sanal ve karma gerçeklik teknolojilerinde yapılan çalışmalar incelenmiştir. Buna göre; otistiklerin bu teknolojilerden terapi alanında öncelikli olmak üzere birçok alanda fayda sağladığı görülmüştür. Bu verilere bağlı olarak otistikleri desteklemeye yönelik çeşitli platformlarda geliştirilmiş uygulamalar, arayüz tasarımları ve etkileşim yöntemlerine bakılarak incelenmiştir. İncelenen uygulamalar farklı amaçlara yönelik çeşitli arayüz tasarımlarını karşılaştırmak amacıyla seçilmiştir. Buna göre incelenen artırılmış gerçeklik uygulamaları şunlardır: Autism Glass Project, Empowered Brain ve otizm eğitmeni Craig Smith'in ARKit uygulama önerileri. Sanal gerçeklik teknolojileriyle geliştirilmiş otistiklere yardımcı proje ve uygulamalardan incelenenler ise şunlardır: Blue Room, FloreoVR, Driving Scenarios in VR ve VW Second Life otistiklere sosyal durumlarda yardımcı uygulama. 2018 Aralık ayına kadar HoloLens cihazı için otistiklere yönelik yayınlanmış beş tane uygulama bulunmaktadır. Bu uygulamaların hepsi araştırma kapsamında incelenmiştir. İsimleri şu şekildedir: Talk for Me, Visual Timers, WeFeel, TalkTablet – AAC/Speech, AuThink pro. Bunların dışında mobil platformlarda da otistiklere yönelik çok fazla sayıda uygulama bulunmaktadır. Bu uygulamalardan çalışmada incelenenler şunlardır: AutisMate, InnerVoice, Kinder Tangram, iPrompts, Proloquo2Go, iDress for Weather, Model Me Going Places 2. Ayrıca arka plan çalışmarı kapsamında karma gerçeklik teknolojilerinin diğer yapay gerçeklik teknolojileri olan artırılmış ve sanal gerçeklik teknolojileriyle birlikte gelişimi araştırılmıştır. Bu tarihsel gelişimi boyunca karma gerçeklik teknolojilerinin kapsamı, kullanıldığı alanlar ve sunduğu olanaklar incelenmiştir. Bu teknoloji üzerine yapılmış araştırmalardan bahsedilerek çalışma kapsamında tercih edilmesini sağlayan özelliklerini destekleyen bulgular paylaşılmıştır. Son olarak da mekansal arayüzlerin özelliklerine ve bu alanda yapılan araştırmalara değinilmiştir.

Yöntem bölümünde önerilen mekansal arayüz araç takımının tasarımı, geliştirilmesi ve değerlendirilmesi ele alınmıştır. Bu mekansal arayüz "Home Base" adı verilen otistiklere uygulanan müdahale yöntemi temel alınarak tasarlanmıştır. Home Base yöntemi, otistiklere ev, okul veya iş gibi özel konumlarda, kendilerini rahatsız hissettiklerinde sakinleşebilecekleri kişisel bir alan sağlamaktadır. Buna göre, bu konumlarda otistiğe özel, onu rahatlatıcı objelerden oluşan bir mekan oluşturulmaktadır. Otistik çevresindeki ses, ışık, renk, hareket gibi etmenlerden rahatsız olduğunda kendi Home Base bölgesinde gidip sakinleşmeye çalışmaktadır. Bu yöntem esas alınarak çalışma kapsamında oluşturulan mekansal arayüz, otistiklere kendilerini rahatlatabilen objelere erişim sağlayabilecekleri bir arayüz olmayı amaçlamıştır. Önerilen mekansal arayüz çeşitli görsel grafik arayüz tasarım kuralları dikkate alınarak tasarlanmıştır. Tasarlanan mekansal arayüz Unity programıyla geliştirilmiştir ve gerekli betikler C# programlama dili kullanılarak entegre edilmiştir. Oluşturulan mekansal arayüzün tasarım ve geliştirme süreci boyunca Microsoft Visual Studio programı kullanılarak HoloLens cihazı üzerinde çalışılabilirliği ve kullanılabilirliği test edilmiştir. Tüm bu testler sonucunda değerlendirmelere hazır bir prototip oluşturulmuştur. Mekansal arayüzün değerlendirilme aşamasında kullanılan yöntemler, kullanıcı arayüzleri üzerine yapılan araştırmalardan derlenerek oluşturulmuştur. Buna göre ilk olarak uzman inceleme yöntemleri olan bilişsel davranış yöntemi ve sezgisel değerlendirme yöntemleri uygulanmıştır. Bilişsel davranış yönteminde bir kullanıcı senaryosu hazırlanmıştır. Hazırlanan senaryo için görev ve eylemlerin gerçekleştirilme sırası belirlenmiştir. Kullanıcı ve arayüz arasındaki etkileşimin değerlendirilebilmesi için her eylem karşılığında dört soru cevaplanmıştır. Böylelikle kullanıcının arayüzü kullanırken karşılaşabileceği muhtemel problemler belirlenmiştir. Sezgisel değerlendirme bölümünde ise hazırlanmış olan prototip, araştırmalar sonucunda belirlenmiş olan görsel arayüz kurallarına göre değerlendirilmiştir. Bu değerlendirme sonucunda arayüzün tasarımsal ve işlevsel eksikleri belirlenerek önerilen mekansal arayüzün bir sonraki versiyonları için muhtemel çözümler üretilerek notlar alınmıştır. Uzman inceleme yöntemlerinin uygulanmasının ardından otistiklerin, karma gerçeklik cihazı olan HoloLens cihazına ve geliştirlen arayüze yaklaşımını ölçmek amacıyla pilot çalışma gerçekleştirilmiştir. Bursa'da bir rehabilitasyon merkezinde gerçekleştirilen çalışmada prototip 6-16 yaşları arasındaki otizmli çocuklar tarafından denenmiş ve HoloLens'e verdikleri tepkiler gözlemlenmiştir.

Sonuçlar bölümünde, yapılan çalışma sonucunda elde edilen veriler paylaşılmıştır. Buna göre uzman inceleme yöntemeleri sonucunda ortaya çıkan, önerilen mekansal arayüze dair problemler listelenmiştir. Buna ek olarak pilot çalışmada otistik çocukların HoloLens cihazına verdikleri olumlu ve olumsuz tepkiler paylaşılmıştır. Otistik çocukların cihaza ve arayüze olan yaklaşımları genel olarak olumlu olarak değerlendirilmiştir.

Tartışma bölümünde ise çalışma kapsamında önerilen mekansal arayüzün olumlu ve olumsuz özellikleri karşılaştırılarak tartışılmıştır. Bu tartışmaya göre, karma gerçeklik teknolojileri kullanılarak geliştirilen mekansal arayüzün duyusal işleme bozukluğu olan otistiklere günlük yaşantılarında yardımcı olabileceğine olumlu olarak bakılmıştır. Ancak karma gerçeklik için kullanılan HoloLens ve benzeri cihazların ağırlıklarının azaltılması, boyutlarının küçültülmesi ve kullanımlarının daha kolay hale getirilmesiyle, otistikler tarafından günlük kullanıma daha çok uygun hale geleceği öngörülmüştür. Çalışma kapsamında yapılan ön çalışma sınırlı sayıda otistikle gerçekleştirilmiş olup, daha çok otistikle beraber çalışılmalı, arayüz ve cihazların faydası gözlemlenmelidir.

Çalışmanın sonunda "My Ho Me" adlı açık kod kaynaklı mekansal arayüz araç takımı, duyusal işleme bozukluğu olan otistik bireylere yönelik karma gerçeklik uygulamalarına entegre edilmek üzere önerilmiştir ve otizmli kişiler için mekansal arayüz tasarlama ve geliştirme konusunun geleceği tartışılmıştır. Bu mekansal arayüz araç takımıyla dünyanın her tarafındaki otizm uygulama geliştiricilerinin hazır temel bir taslağa erişebilmeleri ve karma gerçeklikte otistiklere uygulama geliştirmeye hızlıca başlayabilmeleri öngörülmektedir. Çalışmanın sonuçlarına göre Hololens gibi giyilebilir cihazların otistikler tarafından kullanılabileceği görülmekte ve duyusal işleme bozukluğu olan otistikler için tasarlanmış olan mekansal arayüzün ümit verici olduğu görülmektedir. Değerlendirme sürecinde belirlenen eksik özellikler olmasına rağmen, bu çalışma gelecekteki çalışmalar için bir kılavuz olarak kullanılabilir. Elde edilen değerlendirme sonuçlarının ardından, arayüzdeki görsellerin desteklenmesi için metin eklenmesi ve kullanıcı arayüzle ilgili yardım almak istediğinde ulaşabileceği bir yardım tuşu eklenmesi problemleri çözülerek yeni bir prototip sürümü geliştirilmiştir.

1. INTRODUCTION

1.1 The Scope of the Study

In recent years, the AR, VR, and MR devices started to be recognized by consumers more than before. Although they are mostly used for entertainment purposes, for now, they have the technology to help people with disabilities in many different ways. People with ASD is one of the best possible user groups for these technologies, as they are known to have the tendency using technological devices (Lofland, 2016).

One of the common characteristics of autistic people[1] is social deficits. They have difficulties to understand the emotions and reactions coming from other people. They prefer predictable behaviors, so that is the reason they like computers.

The other well-known characteristics of autistic people are the general adaptation syndrome. People with the general adaptation syndrome feel uncomfortable when they face any changes in a place, on a schedule, or in a person. The adaptation syndrome seen in autistic people is mainly an outcome of sensory processing disorder (SPD). It is reported that 70-95% of ASD population is having challenges processing incoming sensations like light, sound, touch, taste, pain, smell, movement, or temperature (Case-Smith & Arbesman, 2008). They are either hyper or hypo-reactivity to sensory input (Rogers & Short, 2010). People with hyper-reactivity are overly responsive to sensory data, and they may show aggressive behavior in case they are exposed to sensory inputs. On the other hand, people with hypo-reactivity are under-responsive to sensory inputs, and they may seem inactive, uninterested or withdrawn in the event of the one or even multiple sensory inputs (Coffin & Bassity, 2007).

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[1] Why to use the term "Autistic People" instead of Individual with Autism or Person with Autism?

1. Saying "person with autism" suggests that the autism can be separated from the person.
2. Saying "person with autism" suggests that even if autism is part of the person, it isn't a very important part.
3. Saying "person with autism" suggests that autism is something bad–so bad that is isn't even consistent with being a person (Sinclair, 1999).

During the daily routines of people, the environment change, and also the sensory inputs they need to process. The problem is that if autistic people with SPD experience more than one changes consecutively, this may trigger a meltdown. Meltdown is a reaction of autistic people when they have to undergo uncomfortable situations. These meltdowns are affecting the daily life of autistic people and the people around them. Although there are numerous applications available to assist autistic people in those situations, they lack the ability to adjust the space around autistic people immediately to calm them down.

A tool with the capability to customize the space quickly may be a help for autistic people with SPD. Today in 2018, there is an accessible technology called mixed reality to modify the physical space without changing its physical features. It is merging virtual objects with real objects in an advanced space to produce new interactive environments (Brigham, 2017). Also, it differs from VR technology by enabling the integration of real and virtual worlds. So, this study suggests an interface to help the autistic people to be able to manage the meltdowns everywhere using MR technology.

The HoloLens device by Microsoft is one of the first advanced MR glasses released in 2016 operating on Windows platform. It is a stand-alone device with an optical-see-through display which enables the user to see the physical space blended with virtual space. Core features of HoloLens are gaze, hand gestures, voice input, spatial sound, and spatial mapping. Holographic Processing Unit (HPU) helps HoloLens to understand gestures and the direction of the user`s look and adjust the holograms accordingly in real time. It also has spatial sound feature, which enables realistic sound for the holograms.

HoloLens has five visible-wavelength cameras that are tracking the head movements of the user in his/her present space. The one in the center can also take photos or record videos. Moreover, there is one infrared camera and infrared laser projector on the front face to scan objects in the room. There is also the Inertial Measurement Unit which includes an accelerometer, a gyroscope, and a magnetometer to support the head tracking cameras for determining the position and the movement of the user`s head. In that way, HoloLens can understand the virtual objects from the correct perspective, and proportions (Taylor, 2016).

These facilities of HoloLens are recognized as a way to design and develop a spatial interface for people with ASD. Nevertheless, from 2016 to 2018 there have been only five apps[2] developed for autistic people on HoloLens even though there are hundreds of apps developed for personal computers (PC), tablets and mobile phones. The reason for this is the incompatibility of the current interface designs with MR technology. Therefore, there is a need to study on designing three-dimensional (3D) interfaces for autistic people to support developers creating applications in MR.

1.2 The Aim of the Study

A user experience (UX) designer and researcher McKay (2017) mentions the difficulties that autistic people have in one of her articles: "As an autistic person, I experience the world at a heightened level of intensity. I'm hypersensitive to everything in my world: light, sound, colour, textures, shapes, movement, my emotions and the emotions of those around me. Everything hits me in one go like a blastwave and it can take a moment to process and adjust. When I get overwhelmed and the world just gets too much, I experience something called sensory overload. Then I either spin out of control and experience a meltdown or I shut down and completely withdraw". She also complains the lack of assistive technologies to support the sensory differences or to reduce the sensory overload. Thus, in this thesis, we attempt to develop a toolkit to be used in the applications for autistic people with sensory difficulties.

This study implies a spatial interface as an open-source toolkit to be implemented in MR applications for autistic people with sensory processing disorder. In that way, autism application developers from all over the world can have access to a base design template and get easily started developing for people with ASD using MR technologies. This toolkit also aims to encourage other developers to get involved in building solutions for autistic people.

1.3 The Methodology of the Study

In this study, the action research model is adapted as the methodology of the research. The action research method includes identifying the problem about the assisting technologies for autistic people and taking action to improve the life of people with

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[2] Talk for Me, Visual Timers, WeFeel, AuThink Pro, TalkTablet - AAC/Speech.

ASD. The goal of this method is to share the knowledge on recent technologies that can be a benefit for autistic people and related societies.

During the study, the different practices and applications for autistic people are examined. As a result of those explorations, it is found out that there is an intervention method called "Home Base" which can be a foundation of the intended interface design (Myles, 2004; Coffin & Bassity, 2007; Hovorka, 2015; Griswold, 2017). The home base method supports autistic people to function better within their environment wherever they are (Myles, 2005). The contribution of this paper lies on the attempt to develop a MR home base space for people with SPD, that has not been studied earlier. To create a home base, an area within each of the daily used places of autistic people is chosen, and they are equipped with personal objects of autistic people, so they can relax, and keep working on their task in the home base without any distraction.

In the first part of this research, the essential information on autism spectrum disorder are provided with the background study on app interfaces of existing autism applications. Moreover, the related studies on mixed reality and spatial interfaces are explained.

In the second part, the design and development phases of the intended interface are described in detail along with the prototyping process. Throughout the design, the principles for graphical user interfaces (Marcus, 1995; Martin, 1995), the interface recommendations for people with ASD (Pavlov, 2014; Hussain, Abdullah, et.al., 2016; Jordan, Farr, Fager, & Male, 2016), and the guideline of Microsoft for HoloLens (URL-1) are applied to the proposed interface. And it is developed in Unity Game Engine and tested on the HoloLens device.

The proposed interface is evaluated with cognitive walkthrough (Dix, Finlay, Abowd, & Beale, 2003; Galitz, 2002; Polson, Lewis, Rieman, and Wharton, 1992), heuristic evaluation (Shneiderman, 1997; Nielsen, 1993; Pavlov, 2014), and usability testing on HoloLens.

In the end, the results and the future of the study are discussed further.

2. BACKGROUND STUDY

2.1 Autism Spectrum Disorder

Several ingenious people from the history such as Galileo, Einstein, and Edison, are believed to perform some behaviors indicates that they have autism (Armstrong, 2010; Diener, Wright, Smith, & Wright, 2014; Fitzgerald, 2004; Webb, Amend, Webb, Goerss, Beljan, & Olenchak, 2005). Autism spectrum disorder is not an entirely well-studied topic, so it is hard to define it with whole its characteristics. It includes an extensive variety of inability and conditions. First, in 1911, the psychiatrist Bleuler used the term autism to describe a type of childhood schizophrenia. Then in 1940`s two psychiatrists Asperger and Kanner found out that some kids have different symptoms than the others in childhood schizophrenia. In that way, the foundation of autism which we know today has established and related studies have started (Milton, 2012). Since then, the behavior patterns of people on the autism spectrum is still being experimented. But in general, when some behavior patterns are present in a person, then that person called as autistic (Osgood, 2012). According to Lord and Jones (2012), ASD can be characterized as a short-term for some social interaction deficits including repetitive and limited behaviors and interests.

According to Wing and Gould (1979) that every autistic people is not detached and introverted. It is because autism is a spectrum disorder, which means it has types with different strengths or weaknesses. About 1 percent of the world population has autism spectrum disorder (URL-2). It is a lifelong condition found across the age range from children around the age of three to older adults. While people on the autism spectrum have some common disabilities, each autistic people has unique difficulties in their daily life. Thus, assistive applications should offer customization options to every user.

Williams (2004) states that if the autistic kids battle to comprehend their general surroundings, at that point there should be something to support them managing their environment by helping with everyday challenges. Introducing an open door for expanded worlds may well offer new roads to autistic people through an extended feeling of control.

Most of the studies imply that people on the autism spectrum have better visio-spatial skills compared to neurotypicals (Shah and Frith, 1983, 1993; Mitchell and Ropar, 2004; Jung, Lee, Lee et al., 2006). It is because they scored mostly high on Block Design Test which is a test to measure spatial ability and spatial visualization ability. Block Design Test is developed by Kohs in 1923 and still has accepted as the leading non-verbal intelligence test (Clinciu, 2016). Since Kohs, there have been many different versions of the test, but the underlying logic stays the same. During the test, the test-taker needs to rearrange blocks with different colors to match a specific pattern (Figure.2.1).

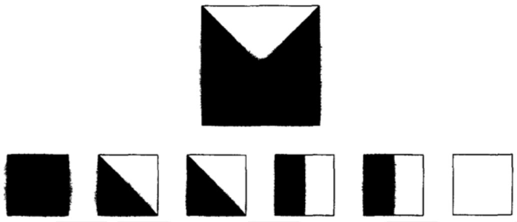


Figure 2.1 : Block Design Test Task Example (Shah, & Frith, 1993).

Even though there are some researchers arguing that spatial visualization ability is not superior for autistic people (Muth, Hönekopp, & Falter, 2014), the fact that most of them showing high-performance on Block Design Test, cannot be ignored. Frith (1991) posits that the success of autistic people on the test can be explained by their detachment. Their social disabilities based on the missing coherence in their cognitive system. In that way, they may also be incapable of recognizing the whole body. Instead, they can detect the details and embedded figures that are generating the complete form. And that may lead to the excellence on Block Design Test.

Considering people with the autism spectrum are having many difficulties during their lifetime, the assistive studies should be focused on their strengths to support them adequately. Since people who have spatial visualization ability or visual-spatial ability can manipulate 2-dimensional (2D) and 3D figures mentally, this ability of autistic people can be considered as a way to improve the current three-dimensional interfaces used in mixed reality environments. Thus, based on those studies, we considered that there is a lack of spatial interfaces to assist autistic people.

The technology based interventions have been found effective for autistic people in most cases (Diener, Wright, Dunn, et.al., 2016; Lynch, 2016; Bresnahan, Burke, Partin, Ahlness, & Trimmer, 2016; Ramachandiran, Jomhari, Thiyagaraja, & Maria, 2015; Ayres, & Langone, 2005; Goldsmith, & LeBlanc, 2004; Charlop-Christy, Le, &

Freeman, 2000; Higgins, & Boone, 1996; Heimann, Nelson, Tjus, & Gillberg, 1995). Therefore, there have been numerous studies about the use of technology for autistic people.

A research group evaluated an animated series called The Transporters created for autistic kids to enhance emotion recognition (Golan, Ashwin, Granader, et al., 2010). In the series, there are eight cars with the faces of actors on them showing emotions to get the attention of autistic children. In this way, they aim to introduce different emotions with facial expressions. Another study on enhancing empathy is about a collaborative virtual learning environment (CVLE) for autistic children (Cheng, Chiang, Ye, & Cheng, 2010). In CVLE, a restaurant simulation is created to practice social situations the empathy needed. A similar study is about a technology-enhanced learning environment called ECHOES to assist autistic children ages between 5-7 for social interaction skills (Porayska-Pomsta, Frauenberger, Pain, et.al., 2012). ECHOES consists of a sensory 3D garden with interactive objects and semi-autonomous virtual characters displayed on a multi-touch LCD display. Children can modify the garden by touching on the screen. The program sets goal for children and provide free exploration of the virtual environment. Other study that intent to assist autistic children for developing social skills has a different approach (Doyle, & Arnedillo-Sánchez, 2011). It suggests a framework for teachers/parents not for the children themselves to design social stories for autistic kids that can help to reveal difficulties the children have during social interactions.

VR is another technological intervention that has been integrated into autism studies with lots of success (Didehbani, Allen, Kandalaft, et.al., 2016). One of the studies in VR is about a VR therapy for social phobia (Brinkman, 2008). Different VR scenarios that can cause anxiety like bus stop, clothing store and reception desk of a restaurant are created, and they are presented to autistic people in a session controlled by a therapist. Other parallel research aims to help young autistic people to beat specific phobias (Maskey, Lowry, Rodgers, et.al., 2014). In the study, the scientists combine the cognitive behaviour therapy with VR environment. They designed unique VR scenes for each phobia the children have and tested them on users. Another research is focused on social cognition training in VR for young adults with ASD (Kandalaft, Didehbani, Krawczyk, et.al., 2013). It aims to enhance social skills by training them in VR for some real-life situations in an office building, a coffee house, a school, a restaurant, etc. The VR environment is formed by Second Life with customizable avatars. Other study is about a driving intervention architecture in VR for people with ASD (Wade, 2015). Its purpose is to design a system that analyzes the behavior of the drivers and provides feedback according to their special needs.

In addition to VR, there have been also studies on AR technologies for people with ASD. Bai, Blackwell, and Coulouris have developed an AR system based on the pretend play behavior (2013). The AR system combines the imaginary object and the real object by overlaying virtual image on the real-world boxes on a display. For example, when the child holds a box tagged as a school, s/he sees himself/herself holding a school building on the screen. Other research posits that AR can help autistic children stay focused (Escobedo, Tentori, Quintana, et.al., 2014). A mobile object identification system in AR is developed to assist children with object identification in a place with the help of digital content. Another study is about the Brain Power AR system which is developed for Google Glass device (Liu, Salisbury, Vahabzadeh, and Sahin, 2017). It provides customizable coaching experiences by using game like AR applications. The aim of the system is to assist children with social behaviors like emotion recognition.

Also, various studies are conducted to test the spatial ability of the autistic people. In an experiment, the researchers analyzed the brain map of autistic people while they are completing tasks (Samson, Mottron, Soulières, and Zeffiro, 2012). The analysis proved that autistic people show better performance at completing visual tasks. They identify the details of objects faster and manipulate them easily. Following this, there is also some articles mentioning that Google SketchUp is widely used by autistic people, helping them to express their ideas visually in a 3D environment (Wright, Diener, Dunn, et.al., 2011).

Even though there are many applications available to autistic users on various platforms, not all the of them provide a convenient user experience. Besides the content of the application, the user interface design should also be considered as an essential element of the application and developed carefully. Therefore, it is concluded that there is a need to design spatial interfaces that enable natural interaction for autistic people. This study aims to develop a spatial interface toolkit that can be implemented into mixed reality application projects for autistic people with SPD.

2.2 Applications supporting people with Autism Spectrum Disorder

Since it is proved on various studies that the most autistic people tend to use visuals along with the technological devices (Behrmann, Thomas, & Humphreys, 2006; Grandin, 2009; Hayes, Hirano, Marcu, Monibi, Nguyen, & Yeganyan, 2010; Mechling & Savidge, 2011; Gonzalez, Martin, Minshew, & Behrmann, 2013; Bradshaw, 2013; Radwan & Cataltepe, 2016), many organizations and developers work on visual supports for autistic people that can be helpful during their daily lives. There are hundreds of applications are available on different platforms for autistic people, nevertheless, most of them are developed for visual schedules to assist completing daily tasks. Also, many of the apps have 2D interfaces used with smartphones, tablets or computers. The applications reviewed in this study are chosen carefully to give a general information about the interfaces used for different actions.

If we look for AR applications for autistic people, there are a couple of important inventions through the years. In 2013, Google published a video showing a Google Glass project for autistic children (Ayres, Mechling, and Sansosti, 2013). Google Glass can scan the environment and show the information present in the place using Augmented Reality through the glasses of the device to the user. Now in 2018, the project seems to be still in development process under the name of Autism Glass Project at Stanford Medicine. It is a behavioral therapy project, involving families of the autistic children in the use of the application. The settings are changed through an Android application by the family or the caretaker (Figure.2.2).

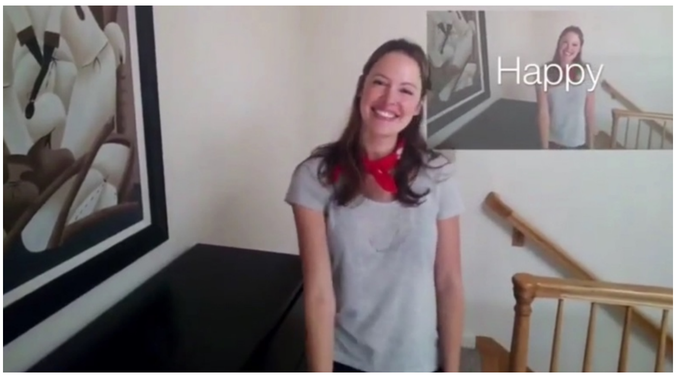


Figure 2.2 : Autism Glass Project at Stanford Medicine (URL-3).

In 2017, a company Brain Power announced an app called Empowered Brain built for Google Glass and other Android glasses that can help autistic people to understand the emotional reactions of people around them (Palladino, 2017). It is a gamified application with colorful smiley icons and true or false games. In time they improved the app and added more features to assist autistic people on their daily routines, and it is available to purchase online (URL-4).

After Apple released ARKit in 2017, autism educator Craig Smith mentioned the possibilities of AR technology for autism on his article (URL-5). One of his ideas is to adapt the traditional visual support tools like visual schedules into AR via ARKit. Visual schedules are one of the essential visual support tools for autistic people. It provides a list of things to do like how to brush teeth or pour a glass of milk. AR can place virtual layers on real objects in the space and show to autistic people what to do with that object. According to Smith, AR can also help for visual focus by highlighting the crucial tools in a room especially in a school environment. Thus, autistic people can focus on the tools they needed for the task on their schedule. He also suggests an application for sensory customization (Figure.2.3). The autistic people with sensory problems can customize the places with light adjustments.

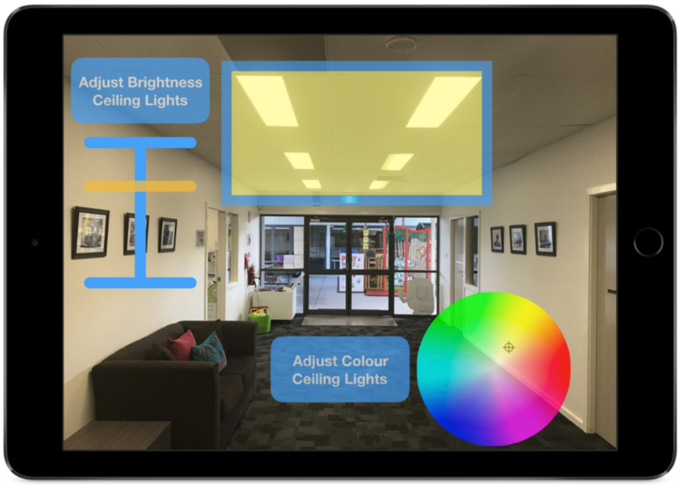


Figure 2.3 : Sensory Customization Application Suggestion by Smith for ARKit (URL-5).

There are also some VR applications developed for autistic people mostly for therapy purposes. Although there have been around since 1996, the bulky VR gadgets back that time was not convenient for the studies in autism. After the release of Oculus in 2012, the number of studies started to rise again (Nunner, 2018). A project called "Blue Room" aims to help autistic children to overcome their various phobias in VR (Maskey, Lowry, Rodgers, McConachie, & Parr, 2014). The application does not require using a VR goggle. It consists of a room with projected 360-degree image on the all four walls. A professional, needs to assist to autistic child in the room to control the application via an iPad (Figure.2.4).

Figure 2.4 : Blue Room (Maskey, Lowry, Rodgers, et.al., 2014).

Another VR project named FloreoVR focuses on assisting autistic children with joint attention, imitation, gestures, and social skills (URL-6). In a VR setting, different scenarios shown to children like sitting on a train or being in a concert to prepare them for confusing situations. The application requires an iPhone 7 or higher, a VR headset, and an iPad. The scenarios are managed by a specialist or the parents from the iPad. Also, a calming experience called Xylophone is included in the application (Figure.2.5), which can be managed by the user himself/herself. In the experience, the music plays automatically when the user moves his head.

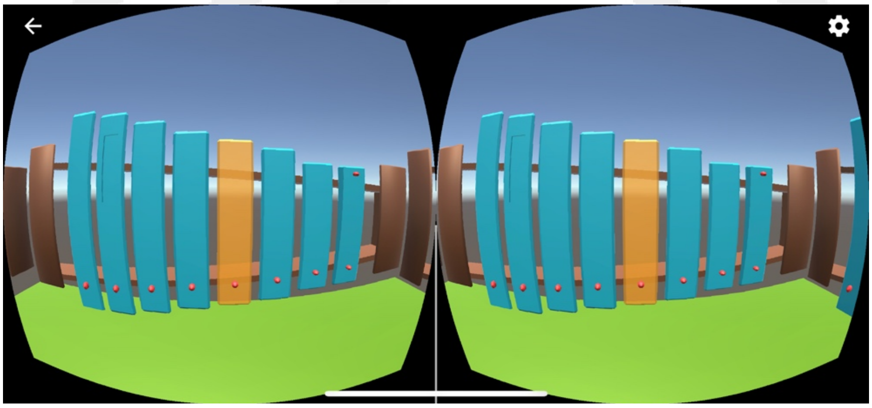


Figure 2.5 : A screenshot from Xylophone application.

In 2015, a VR application was developed at Vanderbilt University to help autistic people to learn how to drive (Wade, 2015). The application can present different driving scenarios to the users while keeping them engaged in the learning process (Figure.2.6).

Figure 2.6 : The driving perspective from Pilot Study (Wade, 2015).

Although it is not a developed VR app, a study was conducted in 2013 to help autistic people in different social situations (Kandalaft, Didehbani, Krawczyk, et al., 2013). They created real-world scenarios like a job interview in Second Life that is a virtual world (VW), and let autistic people experience them, and observe their reactions in VW (Figure.2.7). The result shows that the VR environment helps autistic children to improve social cognitive skills in a safe environment.

Figure 2.7 : VW screenshot of an interview scenario (Kandalaft, Didehbani, Krawczk, et.al., 2013).

Since MR technology and devices are still in the development process, there are just five applications listed on Microsoft Store for autistic people.

Talk for Me application is one of the available apps for HoloLens. It can also be used across different devices like Xbox One, Windows computers, tablets, and phones (URL-7). The aim of Talk for Me is to assist people with ASD or any people with speech difficulties. Although it can be used via HoloLens, the interface is still 2D (Figure.2.8).

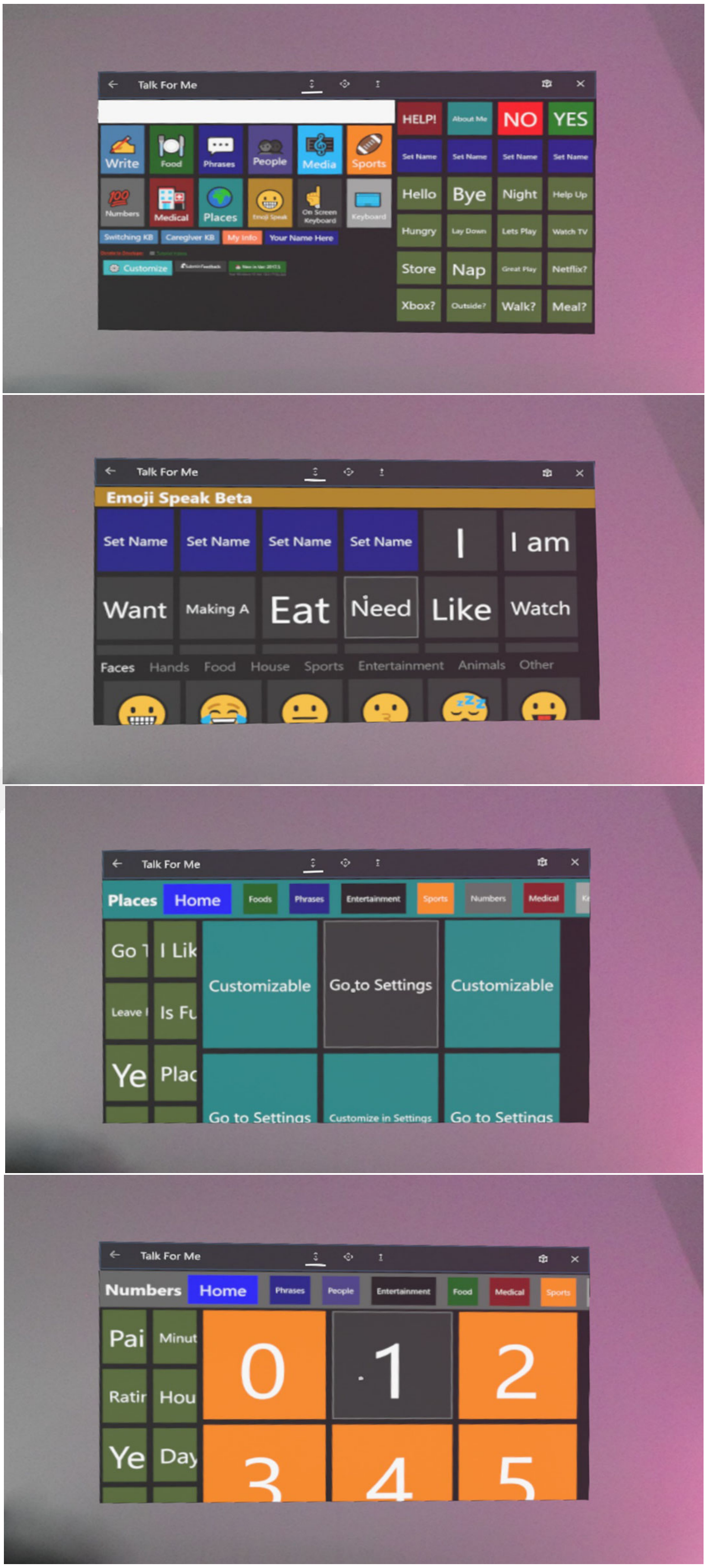


Figure 2.8 : The screenshots of Talk for me taken via HoloLens Device Portal.

The second application is called Visual Timers. It allows users to see the time passing with the help of visuals. In this way, the user can stay calm and patient, while s/ he is waiting for a task to be completed (URL-8). It is also available on PC and Windows mobile devices. The interface of the application is designed as 2D, and the boundaries of the interface is exceeding the screen size, so the user has to modify the screen to see all the content in the interface (Figure.2.9). There is no spatial interaction available. Moreover, there are advertisements on the interface, which can cause distraction.

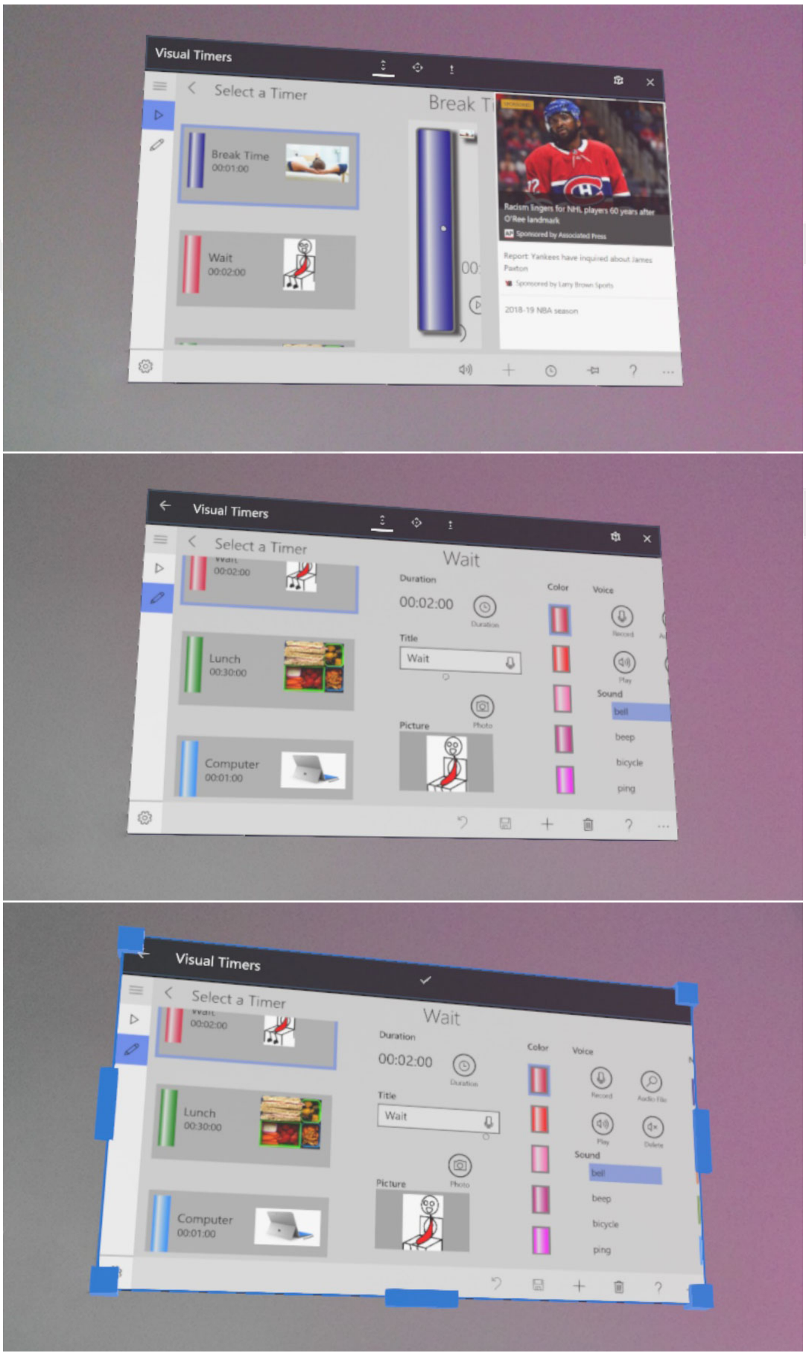


Figure 2.9 : The screenshots of Visual Timers taken via HoloLens Device Portal.

WeFeel is a therapy application which tracks the mental situations of the users like a therapist (URL-9). Except the HoloLens device, it is available on Windows PCs and mobile devices. WeFeel has also 2D interface like the other autism applications on HoloLens and provide a screen-like experience (Figure.2.10).

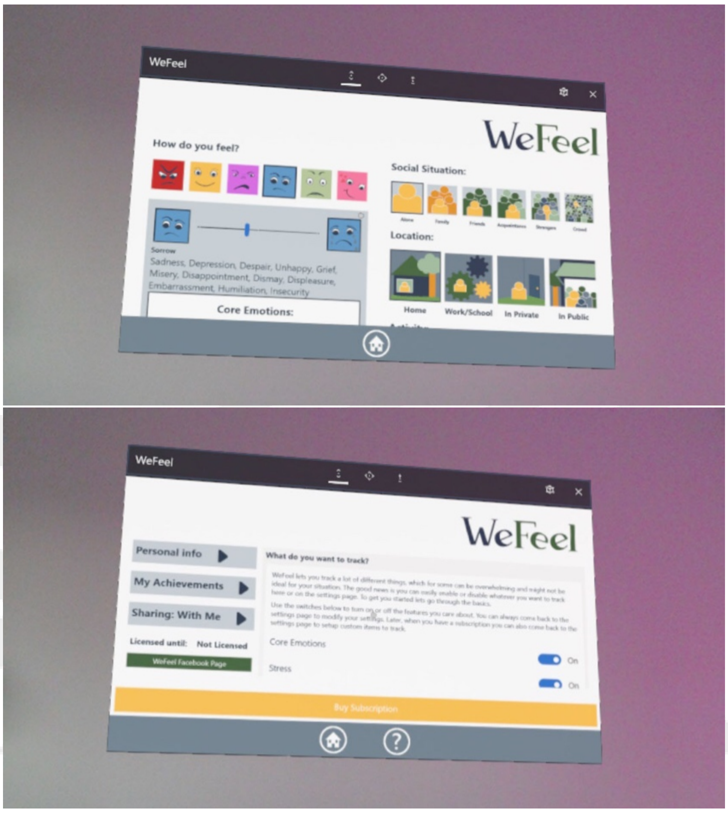


Figure 2.10 : The screenshots of WeFeel taken via HoloLens Device Portal.

Another application on HoloLens is TalkTablet - AAC/Speech. It is an Augmentative and Alternative Communication solution not only for autistic people but all people who have speech and communication problems (URL-10). TalkTablet is available on various platforms including PCs, android phones, iPhones, iPad and Kindle. It has a 2D interface with customization options (Figure.2.11).

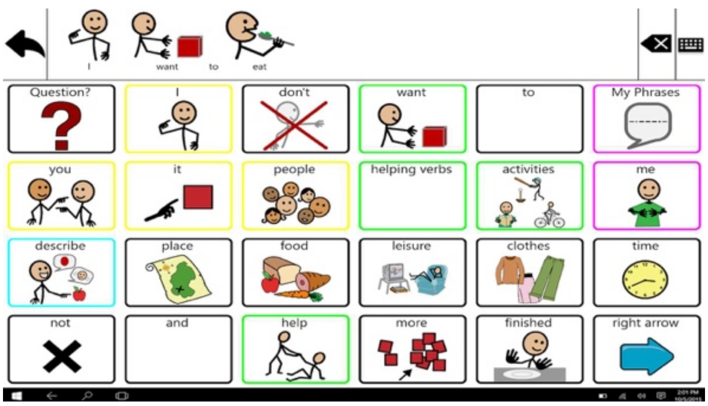


Figure 2.11 : The screenshots of TalkTablet – AAC/Speech (URL-10).

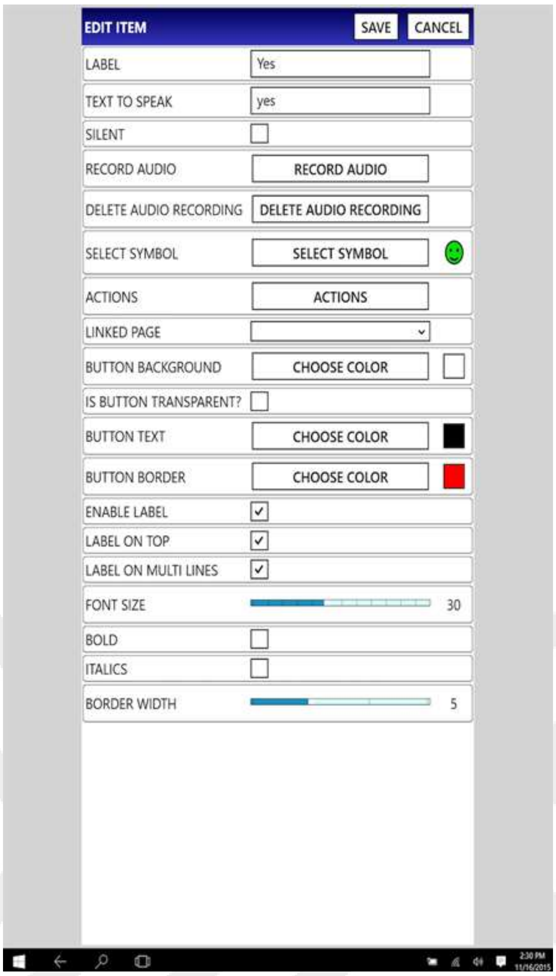


Figure 2.11 (continued): The screenshots of TalkTablet – AAC/Speech (URL-10).

The other application AuThink pro has not been working on HoloLens for a while due to some software problems (URL-11). But the PC version AuThink lite is available for the use. It is an educational application with various tests like matching colors and pairing items for autistic children to develop skills (URL-12). The interface of the application is 2D and same on each platform including HoloLens (Figure.2.12).

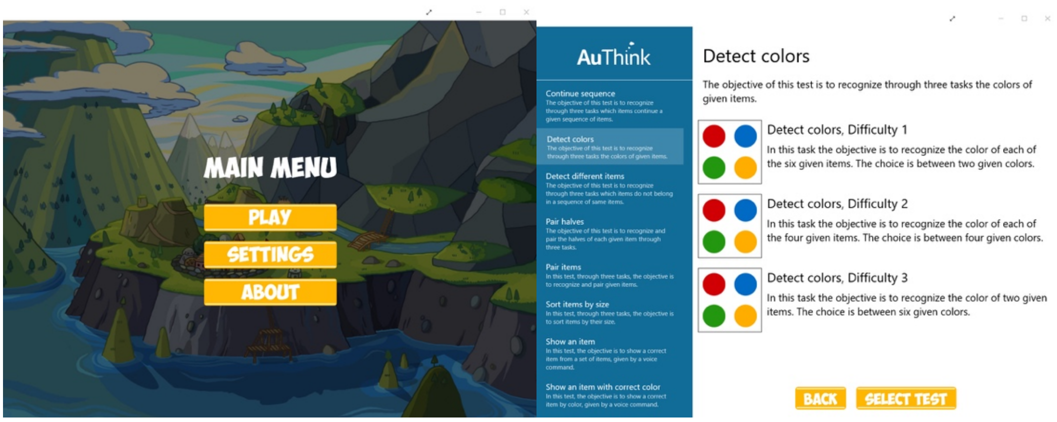


Figure 2.12 : The screenshots taken from the PC version AuThink Lite.

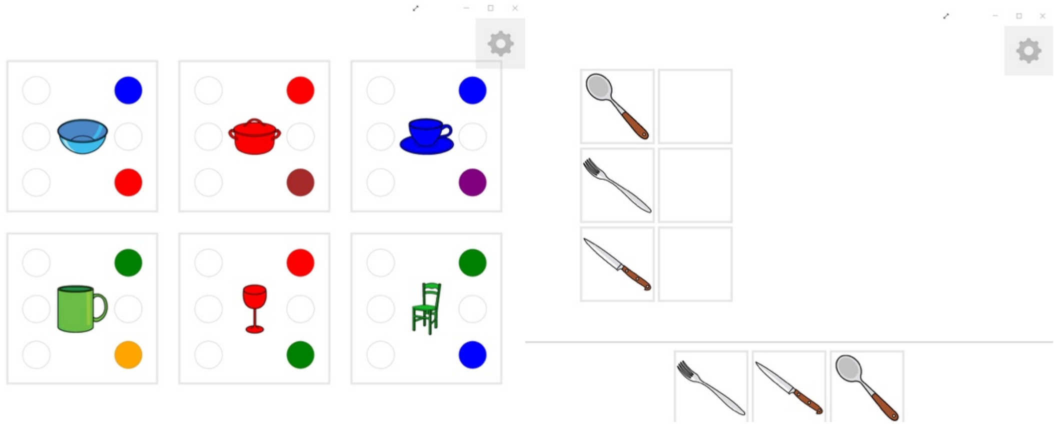


Figure 2.12 (continued): The screenshots taken from the PC version AuThink Lite.

Apart from AR and VR apps, there are many mobile apps for autistic people on the market. AutisMate is an augmentative and alternative communication app available for iPad users, aims to help autistic people to communicate better (URL-13). It has 2D interface containing the pictures of the rooms in the house (Figure.2.13). The room pictures are customizable and can be changed with the pictures of the user`s home. The application needs to be set up by an adult before use. Various tags can be added to the pictures for giving information about the objects in that room, or the tasks can be done with that objects. The general interaction method is tapping on the objects and tags. Sound feedback is used mostly in the application.

Figure 2.13 : The interface of Autismate (URL-13).

InnerVoice app assists non-verbal autistic people with communication problems using visual icons and avatars (URL-14). It is available for iPad and iPhone users. The interface is formed by avatars in 2D (Figure.2.14). Avatars are customizable and replaced with the photo of the user. After the mouth of the avatar is marked, the avatar can talk and express emotions. There are so many texts and buttons in the interface. The user can interact with a tap, hold and drag actions.

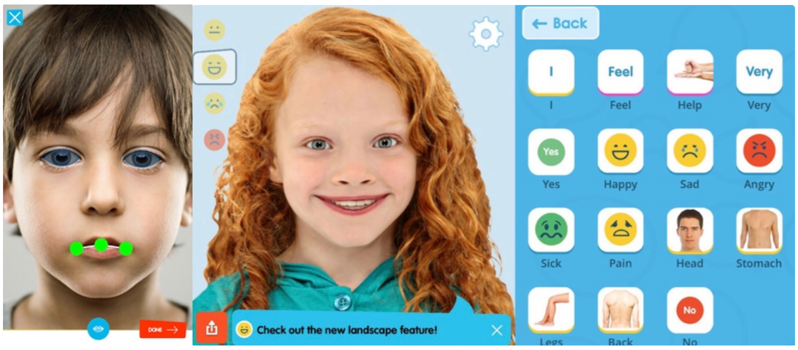


Figure 2.14 : The interface of InnerVoice (URL-14).

Kinder Tangram is another app available on Apple app store. It is an educational app helping not only autistic children but all to build houses with colors, stickers and various other elements (URL-15). The 2D interface is colorful and consisting of puzzles at different levels and art tools to modify the completed puzzle (Figure.2.15). There is little text used in the interface; there are mostly visuals and icons.

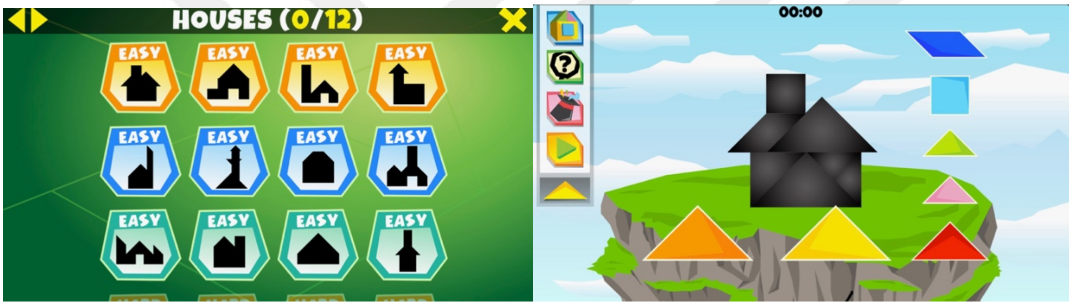


Figure 2.15 : The interface of Kinder Tangram.

iPrompts is a visual schedule app, providing autistic people visual support, available on most of the app stores including Apple, Android, and Amazon app stores (URL-16). It has a simple 2D interface mostly with graphics (Figure.2.16). The visual schedules are formed as a checklist with timer and choice prompts. Nevertheless, there is still no connection to the real places of the user.

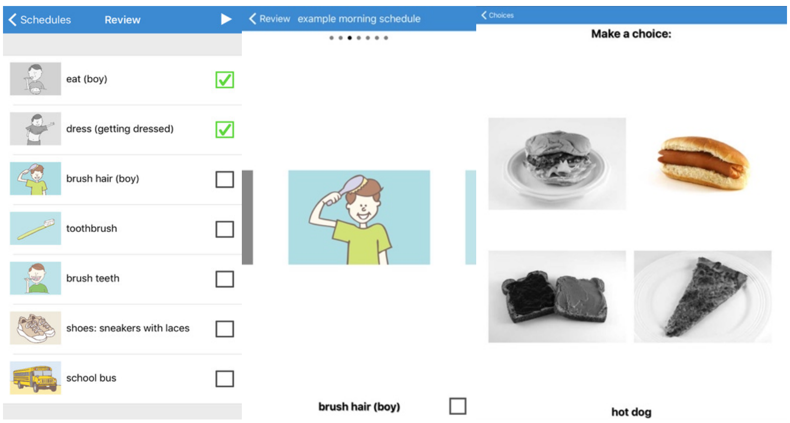


Figure 2.16 : The interface of iPrompts.

Proloquo2Go is another application that can be used on iPhone, iPad, and also Apple Watch (URL-17). It has a 2D interface consists of matching symbols and texts (Figure.2.17). It aims to help autistic children to express themselves with the help of visuals. The button colors and texts are customizable in the application.

Figure 2.17 : The interface of Proloquo2Go (URL-17).

iDress for weather is developed for iPhone and iPad (URL-18). The interface shows a scene with clothes hang in a garden (Figure.2.18). The type of clothes is changing related to the weather, so the user can learn what to wear based on the weather condition. The app is not only for autistic people but everyone. Nevertheless, it is one of the apps listed in autism applications list on several autism institutions. The interface is colorful and fun, but even though it is associated with the environment, it is the same 2D graphics for each location.

Figure 2.18 : The interface of iDress for weather (URL-18).

Model Me Going Places 2 can be downloaded from Apple App Store to iPhone and iPad (URL-19). It has a 2D interface showing the pictures of some places like doctor, mall, and restaurant as a button (Figure.2.19). The user can choose one of them and watch a video showing what to do in those places. Since there are not so many options, the app is easy-to-use; but lacks the interaction with the real places.

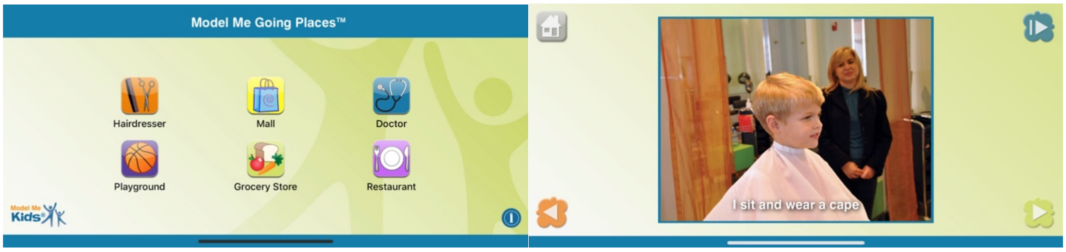


Figure 2.19 : The interface of Model Me Going Places 2 (URL-19).

After the exploration of the applications for autistic people on different platforms, it is concluded that there are no applications with spatial interfaces are present for autistic people on HoloLens platform. Thus, the proposed spatial interface in this study will fill in this space.

2.3 Mixed Reality Studies

The development of AR, VR, and MR technologies have been intersected throughout the history. The first step to these technologies is the invention of Stereoscope by Charles Wheatstone in 1838. It presents the binocular vision which allows users to experience a sense of depth and immersion. In 1929, the first flight simulator named Link Trainer is invented by Edward Link. It simulates a realistic air travel with different scenarios. In 1938, William Gruber and Harold Graves improved the Stereoscope and introduced the View-Master, which is holding 14 images that are showed one for each eye as in total 7 scenes. After a long break, in the mid of 1950s the movie cabinet Sensorama is developed by Morton Heilig. Since it triggers many senses while using stereo speakers, stereoscopic 3D display, fans, smell generators and a vibrating chair, it is one of the closest inventions to the VR technology of 2018. Following Sensorama, Morton Heilig created the first head-mounted display (HMD) which is using the same technology with the stereoscope in 1960. Philco Corporation added the motion tracking to the HMD for military purposes in 1961 to be able to move a remote camera with head movements in dangerous situations.

According to Gobbetti and Scateni (1998), the foundations of VR technology is based on Sutherland's The Ultimate Display research, published in 1965. In this work, Sutherland talks about the basic concepts necessary to immerse into a virtual world of simulation truly. Also, in 1968, Sutherland and his student Sproull developed the Sword of Damocles which is the first HMD connected to a computer. The device was quite heavy and used by suspending from the ceiling. After a couple of years, Krueger set up an artificial reality laboratory called Videoplace in the mid of 1970s. Videoplace project enables people to communicate remotely in a computer-generated virtual environment.

Finally, the term virtual reality was first used by Lanier in 1987. He developed a glove named Dataglove with Zimmerman and an HMD called EyePhone at his company Visual Programming Lab (VPL). VPL is the first company that sold VR goggles. Happening next in 1990, Caudell from the Boeing used the term augmented reality for the first time to describe a digital display used by aircraft electricians that blends virtual graphics onto the real world. In 1992, Rosenberg developed Virtual Fixtures which is an AR system for the Air Force to operate a remote machine via telepresence and transparent interfaces. CAVE VR system is also developed in 1992 by Chicago Electronic Visualization Laboratory. It is a room formed by flat panel displays with projection systems. The users wear 3D glasses in CAVE to immerse the visuals on displays. In 1993, SEGA introduced a VR headset with LCD display, stereo sound and head tracking feature. But because of the technical issues, they could not release the consumer version of the device. And in 1994, Martin created an AR performance Dancing in Cyberspace showing acrobats dancing within virtual objects projected on the stage.

Eventually, the first academic paper that defines the mixed reality technologies published by Milgram and Kishino in 1994. The paper suggests a virtuality continuum (VC) graph showing the positions of different realities to each other (Figure.2.20). According to VC, a mixed reality environment is a hybrid space between the real and virtual environment, presenting real and virtual objects together on a single display. Milgram and Kishino have also grouped the hybrid displays that exist in 1994 to distinguish MR interfaces related to their definition. During this process, they categorize the displays depending on dominance of the world being experienced either real or virtual. If the primary world is the real world, they called the display as AR. But if the primary world is the virtual world, they called it as Augmented Virtuality (AV). However, they assume that during time, the line between those two terms can be blurred with developing technologies. Nevertheless, the term mixed reality stays valid, since it covers both AR and AV. That is the main reason why the term Mixed Reality technologies are used in this study.

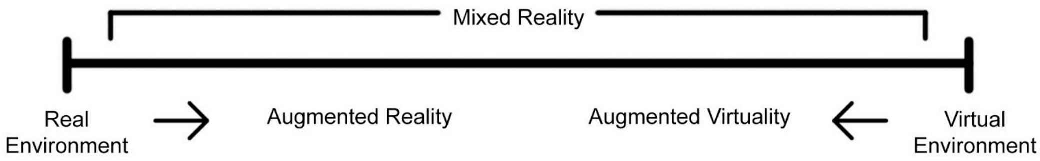


Figure 2.20 : Virtuality Continuum Graph.

According to Sutherland (1965), the screen is like a window to the virtual world, and the challenge is to make every element in the virtual world as perceived as real. Since the 1960s this challenge has been investigated, and different solutions have been developed, but the VR, AR technologies were confined to research laboratories due to the dependency on large-sized advanced computers. With the appearance of Oculus Rift VR on Kickstarter in 2012, it has been seen that VR technology can be brought to a transportable dimension that can be used outside of the laboratories. Thus, the VR industry has been mobilized, and since the purchase of Oculus company in 2014 by Facebook, the technology used only for research purposes until this year became also available for commercial use. AR technology has become first available to the public also in 2014 via Google Tango project, but it was limited to specific smartphone and tablet models. Later in September 2017, ARcore by Google for brand new Android smartphones and tablets and ARKit by Apple for the latest iPhones and iPads launched to the market.

In 2016, Microsoft has launched the developer version of HoloLens mixed reality headset, and in 2017, released other Windows Holographic devices[3]. With the help of mixed reality technologies, it is thought that the interaction with virtual objects in the physical world can be more natural, which may increase the possibility of users to prefer this technology in many areas (Khan, & Nikov, 2011).

The most prominent difference of mixed reality devices such as HoloLens compared to other devices using artificial reality technologies is that they are frequently mapping the user`s surrounding in 3D (Brigham, 2017). It can be assumed that this feature facilitates an accurate physical interaction with the users. The sensors on HoloLens can detect the area and also objects in that space. 3D Spatial mapping combines the

[3] Samsung HMD Odyssey, Dell Visor, HP Headset, Lenovo Explorer, Acer Headset.

physical and virtual world by teaching holograms both of the environment. Thus, holograms act like this mixed world is the only place they exist. It is also called as blended reality by some researchers to bring the attention to contextual reality gap which has occurred when people are using technological devices in the physical world (Waterworth, & Hoshi, 2016). In this way, mixed reality can also reduce the distraction by gathering all the digital and physical information around the space in one place.

MR technology is often confused with AR technology. However, based on the Milgram`s paper (1994) the term MR technology is a spectrum that already comprises AR itself. Nevertheless, the types of the devices and interactions are changing throughout the mixed reality spectrum. In 2018, the definition of Mixed Reality spectrum consists of a wide range of technological developments from the digital overlays through the mobile phones to the advanced virtual reality systems with tangible interfaces. In the last ten years from 2008 to 2018, there have been few studies about the various devices and interaction methods in mixed reality technologies.

The main topics of the studies are mostly training for industrial, military or medical purposes, social presence, haptical interfaces, interaction techniques other than technical ones aiming to develop MR technology and devices further. However, all of them support the definition of Mixed Reality Technology and its spectrum by mentioning Milgram`s research published in 1994.

One of the technical studies by Thöner and Kuijper (2012) focuses on creating a homogeneous scene with objects from different realities via the high-quality illumination method for virtual objects. In that way, virtual objects can look more realistic and blend with real objects. The other technical study by Knecht, Traxler, Mattausch, & Wimmer (2012) is also about the illumination techniques in MR environments. They suggest that the MR technology is an effective way for virtual presentations in areas like architecture, marketing, and sales; but the illumination techniques in MR should be further developed to create real-like illusions of a mixed space. Abate, Narducci, and Ricciardi (2014) have a different approach to improve MR environments. They posit that the video-based see-through approach is the foundation of the illusion of the virtual-real co-existence in the mixed space. In this approach, the virtual objects are rendered and superimposed onto the physical objects in real-time. On the other hand, Zhou, Bian, and Zhuo (2017) introduce a projection method for mixed reality technology. In the projection method, multiple real-time videos are coming together and projected onto a physical model. So, they suggest that the appearance of the model surface can be constantly updated with the use of different MR technologies via projectors, optical elements, transparent screens, and holograms. Thus, multiple users can experience it without wearing any personal equipments.

Some of the studies on tangible interfaces are also taken advantages of MR technologies. A study adopted a MR system with a video see-through mechanism that visually changes the appearance of touchable real objects by superimposing virtual contents (Hashiguchi, Sano, Shibata, et.al., 2014). They call this method as MR visual stimulation. Other study by Hiroshi (2008) explains different uses of tangible user interfaces. It mentions the tangible telepresence which is working with haptic inputs to create haptic outputs remotely. Although MR term is not indicated directly in the study, the study is very similar to" Virtual Fixtures" by Rosenberg (1992). The MR technology used in those studies are defined as immersive augmented reality which is covered in the mixed reality spectrum. Another study analyzes the tactual impression by audio and visual stimulation in MR environment (Kagimoto, Kimura, Shibata, et.al., 2009). They assume that when the appearance of a real object is altered by superimposing digital images on it, the tactual impression by the user also changes. It shows that MR technology can affect the perception of the user with visual stimulations and audio. Moreover, the study on cognitive rehabilitation with MR presents the interaction between real and virtual worlds in MR as a challenge (Beato, Mapes, Hughes, et.al., 2009). So, they create a mixed environment which provides tactical response to the user. They covered some objects in the room with chroma-key blue paint, so the appearance of the real objects is superimposed with virtual objects in a mixed space. And the user can touch the real objects while seeing the virtual counterparts.

The studies related to interaction techniques in MR technologies search for providing better embodiment methods in mixed environments. In a study conducted by Lindgren and Johnson-Glenberg (2013), it is assumed that MR environments can provide natural interaction via gesture inputs and that can be useful for students in learning activities. Other study is about an interactive MR installation for Alice's Adventures in Wonderland story (Nakevska, Hu, Langereis, et.al., 2012). They created a mixed environment that reacts the users` inputs like motion or the changes in the real environment. Another study by Wang (2011) has a different approach to telerobotics which is the use of human-robot interaction with mixed reality technologies. They propose that MR is actually an interaction concept looking for different methods to combine virtual and real worlds. They posit that MR is a tool to define the meeting points of the virtual and real world. And based on that idea, they introduce robots as a mixed reality device to connect virtual and physical spaces. In the Bubblegrams project, they present a robot which can generate floating bubbles reflecting information onto a physical space. In their second project called “Thought Crumbs”, the digital information is placed in a real-world location for a robot to use them to show the user.

Furthermore, there are studies on social presence in mixed reality. The study by You and Thompson (2017) introduced a system for a collaborative mixed reality visualization, enabling both in-situ and off-site users to simultaneously interact with and visualize science data within mixed reality realm. And the study named “Repeat after me: Using mixed reality humans to influence best communication practices” presents a technique to display virtual humans on a display (Cordar, Wendling, White, et.al., 2017). With this technique even though the display is a traditional television screen, it looks like see-through display. So, the virtual human is experienced like present in the real space. A study on MR telepresence platform introduce a MR system to exchange emotions between remote places (Lee, Ha, Lee, et.al., 2017). The user experiences a live remote scene via VR head-mounted display, while the VR head-mounted display can get the sensory information of the user and send it to a holographic display in the remote scene for the other users in that room. Another study presents a Kinect-enabled mixed reality environment to interact with virtual world with the movement of the user (Ke, Lee, & Xu, 2016). So, it is assumed that the social presence can be enhanced with the integration of the real body movements into the virtual scene.

Architecture related studies are mostly concerning artistic and design perspective of mixed reality (Morrissey, 2014; Nakevska, Hu, Langereis, & Rauterberg, 2012). It is assumed that mixed reality can change the design processes in architecture by making it more customizable according to the needs of the user (Löffler, Tholt, & Šimkovič, 2016). As reported in” The Mirror World: Preparing for Mixed-Reality Living” research, some smart environment scenarios can be created, that enable the enhancement of physical spaces via mixed reality technologies (Ricci, Piunti, Tummolini, & Castelfranchi, 2015). The most inclusive architectural study in mixed reality is conducted by Wang and Schnabel. Their book is published as “Mixed Reality in Architecture, Design and Construction” in 2009. The book addresses collaborative design in mixed reality, simulation examples in architecture via mixed reality, the use of MR on construction site, and the use of MR in architectural education by visualizing structures.

In some studies, mixed reality technologies also referred as spatial augmented reality. It is stated that new display technologies like mirror beam combiners, transparent screens, holograms and video projectors use the ability to align optical elements spatially, thus these technologies can be called as spatial augmented reality (Bimber, & Raskar, 2005). Mixed reality or spatial augmented reality enable the materialization of an alternate world in different ways like optical, acoustic and haptical. Illumiroom by Microsoft can be considered as an optical materialization project (Jones, Benko, Ofek, & Wilson, 2013). This mechanism makes the peripheral projected illusions possible via a television screen while the user playing games. The projected visuals can change the appearance of the space, so it can enhance the experience of the user. Another project called Filmachine can be regarded as an acoustic materialization project. It is a sound installation that generates virtual 3D sound structures in physical space (Ikegami, & Shibuya, 2008). The system places the 3D sound structures related to sound levels similar to a 2D sound visualization. In that way, the audience can experience the music at different levels in different positions. In addition, there is a study called Virtual Haptic Radar about a wearable device prototype which can be examined as a haptic materialization project. This device is developed to help actors to recognize the virtual objects in the physical space during filming process in a virtual studio (Cassinelli, Zhou, Zerroug, & Ishikawa, 2011). If the device detects that the user is in the force field of the virtual object, it vibrates to warn the user.

Cheng (2017) mentioned the relationship between mixed reality and physical spaces in one of his interviews by asking that if all the walls, ceilings, floors or tables in a room were interacting rather than just stationery, how people would naturally interact with them without using a mouse or a keyboard. He thinks that mixed reality glasses are the best tool that allows people not only to communicate with the room around them but to interact with the whole world. But to be able to go deep into that question further investigation should be done about the possibilities of the 3D interactions through the spatial interfaces with present mixed reality devices.

There are also different aspects on the Mixed Reality term that need to be addressed. The study by Taçgın and Arslan (2017) shows that most of the Computer Education and Instructional Technologies (CEIT) postgraduate students have no idea about mixed reality and there are two questionable impressions derived from the answers of the students. These impressions are that the mixed reality effects the physical reality and the two-sided reality affects one another. The research paper by Brigham (2017) tries to make clear the content of AR, VR, and MR by explaining that MR is an effort to mix the best features of both AR and VR. It is posited in the study that MR enables the user to experience the depth and perspective of the virtual objects. Therefore; while the user is coming closer to the virtual object, the object is getting bigger; and while the user is going away from it, the object is becoming smaller. It is also mentioned in the study that there are some claims about the use of the mixed reality term. It is claimed that the term might be used as a marketing strategy to separate specific AR and MR devices. But Brigham explains that there is no need to differ them, since the MR technologies cover them all. Waterworth and Hoshi (2016) have a different approach to these misconceptions. They assume that, there are different kinds of mixed realities presenting different interactive experiences. There are sensor-based methods to interact with virtual objects via the manipulation of real objects (see Hiroshi 2008). There is also sensor implemented environments or mobile phones with built-in sensors and many more. The study suggests that although there are various methods, there is still not a clear connection between these interactive media and the users in the real space. Thus, the interaction methods in MR need to be further investigated. Other study named" Blurring the Lines between Digital and Physical World" (Richir & Pallot, 2016) describes the capacity of MR technologies. According to Richir and Pallot, MR provides the technology to scan real objects or elements in the physical space and import them into the virtual space. That`s why it is not only augmenting reality but also augmenting the virtuality.

2.4 Spatial Interfaces

From the moment humans are born, they perceive the space in 3D due to biological constraints which cause them to think spatially. The areas we define as three-dimensional spaces consist of trivariate models of the physical world. These three variables emerge due to combinations of length, width, height and depth values. It has been discovered that in the time of the first perspective paintings, people could perceive a picture as reality due to spatial integrity, and to immerse to that image, it was necessary to see two dimensions of that image in one continuous, homogeneous, three-dimensional space (Wertheim, 1999). Thus, even though perspective paintings are two-dimensional, they can be considered as the first step towards the idea of virtual worlds.

Spatial Interfaces are three-dimensional interfaces that enable the virtual objects to be positioned in 3D space around the user. The spatial interfaces can facilitate the natural interaction of users with virtual spaces without leaving the physical environment they are in by providing the integration of virtual and physical spaces.

In AR, VR and MR applications, communication between the user and the artificial reality devices is provided by two- and three-dimensional interfaces. However, every three-dimensional interface does not offer an excellent interaction with the user and cannot immerse the user into the virtual space. One of the reasons is that not every element, which is defined with all its dimensions in the space, allow the user to experience the actions and interactions like in his/her real life. In some applications, photographs, and video images shot with a 360-degree camera defined as three-dimensional. Technically, the user is in a virtual reality three-dimensional space while using these applications. But they cannot walk around or behind the objects in the virtual space; they cannot examine them from every angle. This situation prevents the user from feeling as if the virtual space is real and makes it difficult to immerse in that space. With the help of the 3D spatial interfaces, it is planned to make the user feel as if s/he is present in the virtual world.

One of the key features that distinguish three-dimensional interfaces from two-dimensional interfaces is that users can experience virtual or physical three-dimensional spaces and feel like they are moving in these spaces. Thus, while three-dimensional interfaces are being designed, the knowledge of Spatial Perception, Spatial Cognition, Navigation, Movement, and Manipulation need to be considered (LaViola, Kruijff, McMahan, Bowman, & Poupyrev, 2017). With a three-dimensional interface in mixed reality, it is possible to assure the spatial perception and awareness of the user even in an empty room. Three-dimensional interfaces can connect the user directly to space. In this way, they can be called spatial interfaces.

After Ivan Sutherland's research about a head-mounted three-dimensional display in 1968 and James Clark`s work about designing 3D surfaces in 1976, there have been numerous studies investigating the possibility of the integration of virtual worlds with spatial interactions (Jackson, 2014). According to Ens and Irani (2017), spatial interfaces can be designed with combinations of two-dimensional interfaces placed in the third dimension. They have described these theories in the Ethereal Planes

Metaphor project. Ethereal planes are generated by projecting two-dimensional interfaces using AR, MR glasses, or projectors to real spaces. These planes are located in the physical space concerning each other and the real objects present in the physical space. In that way, they are providing interaction to the user (Figure.2.21). In mixed reality, the concept of spatial interface is a three-dimensional interface that is proposed as an alternative to ethereal planes metaphor, allowing the user to interact directly with space without the need for two-dimensional interfaces. According to an experiment in the gaming industry, when participants use three-dimensional interfaces while performing tasks that need three-dimensional interaction, they play better than when they use two-dimensional interfaces (LaViola, Kulshreshth, & Pfeil, 2017). Thus, in the scope of this research, it is assumed that the spatial interfaces provide better interaction with space for autistic people.

Figure 2.21 : Ethereal Planes (Ens & Irani, 2017).

Since technological devices have become a part of people life, studies on user interfaces have been increased. Nevertheless, since three dimensional and spatial interfaces are recognized with artificial realities, they are still new topics, which need to be investigated further.

Bowman, Kruijff, LaViola, and Poupyrev have studied input and output devices for three-dimensional interfaces and interaction techniques in their study “An Introduction to 3D User Interface Design” in 2001. They sum up the interaction techniques in three categories: Navigation, selection & manipulation, and system control. Navigation is thought as the primary interaction in three-dimensional space to move and explore around. There are five interaction types within navigation that can be used according to user needs. These are physical movement, manual viewpoint manipulation, steering, target-based travel, and route planning. Physical movement allows users to travel free in three-dimensional space. Manual viewpoint works with hand motions of users. Users should operate with their hands to travel in three-dimensional space. Steering functions with the gaze of users. Users should stare at the point they want to travel. Target-based travel is like teleportation. It allows users to teleport to a specific location in three-dimensional space. Moreover, in route planning, users should draw a movement path for themselves; then they automatically are traveled on that route. The second main interaction technique is called selection and manipulation. It primarily consists of the selecting, positioning and rotating of objects. So, the last one is system control which allows the user to change the mode of the system or interaction by using commands. Researchers in this study also categorized system control in four-part: graphical menus, voice commands, gestural interaction, and tools. Adding that combined techniques can be used in one application.

Berthaut and Hachet (2016) assume that there are not so many studies about three-dimensional and spatial interfaces that aim to improve creative and emotional user experiences. Thus, they present a spatial interface project for musicians. The intended application allows musicians to connect three-dimensional objects to sounds. In that way, musicians can compose music by interacting 3D objects around them. It is also possible to compose as a band working together with the spatial interface. Researchers in this study believe that spatial interfaces should be explored further to provide more interaction between musicians and the audience.

Spatial interfaces can also extend the spatial information and cognition by providing clues or hidden information to the user. So, the user can be more aware of the content or objects within the space. A study called "The Laser Aura" aims to build a wearable device like prosthesis which can show the emotional state of the person wearing it (Cassinelli, Zhou, Zerroug, & Ishikawa, 2011). In that way, people from outside can understand the mood of the person with the laser aura, and act accordingly.

The virtual layers added to the physical spaces can improve the real-world values as well. There are some studies which are not directly related to the spatial interfaces in mixed reality but connected in a way that they are affecting the spatial interfaces in the real world. So, their systems and ideas can be applied to the spatial interfaces in mixed reality. A study about pedestrian flow shows that optical illusions added to space, can affect the perception of the people and alter the direction they walk (Furukawa, Yoshikawa, Hachisu, Fukushima, & Kajimoto, 2011). Spatial interfaces can obtain the same effect through mixed reality technology. The MR googles can help to navigate through the streets, control the pedestrian flow, and show a different perspective of the physical spaces to the pedestrians.

There have also been studies about natural interfaces that are investigating the ways of natural interactions via spatial interfaces. The term natural comes from the fact that the human brain is evolved to think spatially. As Steinberg (2012) points out, the golden rule of the natural interfaces is the ability to interact with the virtual world spontaneously. These interfaces are immediately available for use, meaning there is no need for an introduction or previous experience to use it. It is thought that since people are used to interacting with 3D space in real world, spatial interfaces can provide a natural interaction. For this reason, it can be suggested that spatial user interfaces that combine virtual spaces with physical spaces are also natural interfaces. In this study, we propose a spatial interface which provides natural interactions with navigation, selection & manipulation, and system control features to the user in a mixed 3D environment.

3. METHODOLOGY

Based on the framework (Figure.3.1), a need for a Mixed Reality tool is identified to assist autistic people with SPD 'enabling them to continue their daily lives without meltdowns in any place' (Williams, 2004; McKay, 2017). Since it is concluded that MR technology has the ability to create a hybrid space for people to see the real and virtual space at the same time (Khan, & Nikov, 2011), it is suggested as a base technology for the proposed interface. According to the researches done in the field, an intervention method called "Home Base" for autistic people with SPD is recognized for the design approach of the interface. Home Base method provides a personal space to autistic people in specific locations like home, school or work to take a break from a stressful situation within a calming space (Coffin & Bassity, 2007).

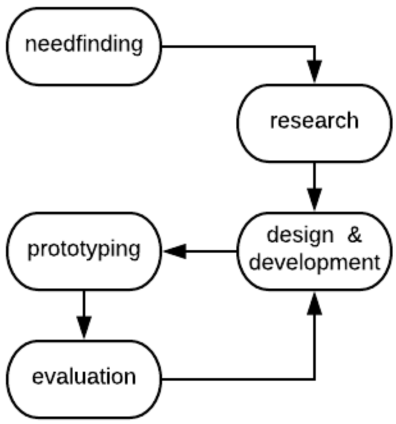


Figure 3.1 : Methodology Framework.

Then, some of the existed applications for autistic people running on different platforms are examined. During the design process, the principles for graphical user interfaces (Marcus, 1995; Martin, 1995), the interface recommendations for people on ASD (Pavlov, 2014; Hussain, Abdullah, Husni, Mkpojiogu, 2016; Jordan, Farr, Fager, & Male, 2016), and the guideline of Microsoft for HoloLens are used as the basic rules for the intended interface design. Thus, we designed a prototype based on those frameworks done by prior researchers Nielsen (1993), Shneiderman (1997), and Pavlov (2014) as explained in the below section.

A spatial interface is designed and developed in Unity Game Engine along with the Microsoft Visual Studio. In Unity, the elements of the interface are created, and the necessary scripts are implemented in C# programming language. The spatial interface is constantly tested via Microsoft Visual Studio on HoloLens to examine the quality of the design.

Then, In the evaluation process based on the studies about user interfaces (Nielsen, 1992; Nielsen, 1993; Shneiderman, 1997; O`Connell, 2016; Khajouei, Esfahani, & Jahani, 2016), at first, expert review method is applied by using cognitive walkthrough (Dix, Finlay, Abowd, & Beale, 2003; Galitz, 2002; Polson, Lewis, Rieman, & Wharton, 1992) and heuristic evaluation considering the eight golden rules by Shneiderman (1997), the usability principles by Nielsen (1993), and the interface recommendations for people on ASD by Pavlov (2014). After some remote meetings, Bursa Doruk Special Education and Rehabilitation Center (Ozel Bursa Doruk Ozel Egitim ve Rehabilitasyon Merkezi) in Bursa, Turkey is selected for the pilot study. The prototype is tested on 12 autistic kids between the ages 6-16. Each participant used the HoloLens device for 1-2 minutes to get the know the device itself, gaze, air tap hand gesture and experience a glimpse of the objects in the interface. During the pilot study, participants tried to perform air tap to select and move an object from the interface. The experiment scene is recorded via a Samsung 360-camera and an iPhone camera, and the HoloLens display is also connected to the HoloLens Device Portal. In this way, the live camera view is made available to observe the user experience via screen-recording. In-between the user trials, the state of the scene is inspected, and the changes are noted.

For the proposed interface “My Ho Me” is chosen as the name of the toolkit. Although the end product of this study can be used from all ages, autistic kids are thought of as the primary users. Thus, the elements in the interface are chosen to be fun and kid-friendly considering the related studies on the interface design principles for people on ASD (Kamaruzaman, Rani, Nor, & Azahari, 2016; Pavlov, 2014; Mejía-Figueroa & Juárez-Ramírez, 2013). Moreover, since one of the common symptoms of autism is also the adaptation syndrome (Schwenck & Freitag, 2014), the interface can also be used by most of the autistic people with environmental adaptation difficulties. In the following sections, the design and development process of My Ho Me is explained in detail.

3.1 Design

3.1.1 Interface Design

My Ho Me represents my home, but it is broken into pieces to be read easily by most of the people. The design of the holograms in the interface determined considering the traditional Home Base method. When the autistic people feel uncomfortable in a place, they want to go to their home base to get their favorite objects and relax. Nevertheless, each person has unique favorite objects. So, the holograms in the sub-menus are put as placeholders in the proposed interface, every one of them can be customized according to the user's choices if it is needed.

Holograms are the main components of a spatial interface for HoloLens. A hologram is made of light and added to the field of view. The users can see both the hologram and their surroundings just like that. There are many options to create hologram appearances. They can look like real, but also, they can be cartoonish and ethereal. However, each hologram can interact with the user directly by following the movement of the user. They can also interact with the real-world objects via occlusion feature. Since the HoloLens maps the surrounding of the user, every object in the real world is detected and interactable. For instance, a hologram can detect where the wall is and can be broken when it hits the wall.

A spatial interface should be formed with some key design points similar to the real-world characteristics to make the user interaction natural. These important points can be listed as depth cues, use of light, interaction feedback, and text clarity (URL-20). Nevertheless, the essential three notions for the spatial interface design are space, motion, and flow (O`Connell, 2016). While designing spatial interfaces the boundaries of the screen need to be disregarded, and the interface should be considered as a whole within and out of the display. Also, the holograms need to reflect the real word objects as much as possible. To success that occlusion; feedback system, lighting and shadows should be considered.

The interface layout consists of a main menu button and a move/stop button attached to the main-menu button to change the location of it in the space by using spatial anchors. Therefore, the menu can stay in the same place, when the user come back to that space. There are six toggle-buttons in the main-menu: build, laugh, live, favorites, delete and mute. Representative visuals of the buttons are chosen to reflect the functions of the buttons (Figure.3.2).

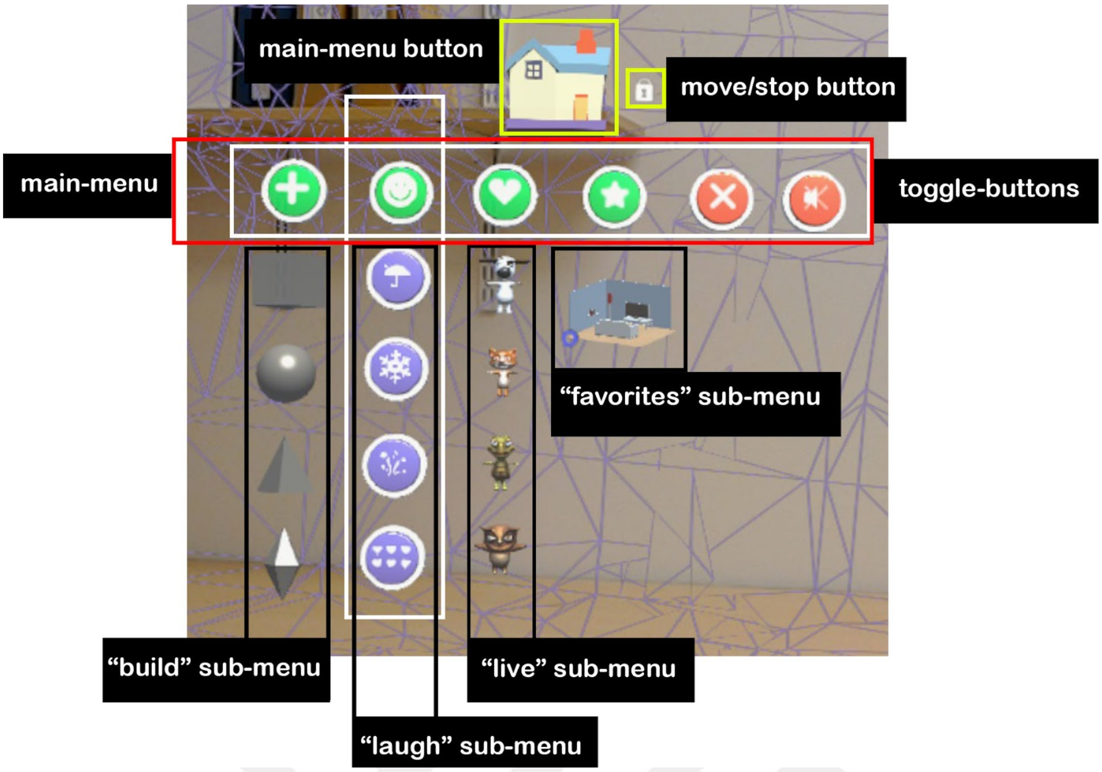


Figure 3.2 : The components of the interface.

The main-menu button is a colorful 3D home hologram. The move/stop button is presented by unlock and lock holograms to represent lock/unlock process in the real world (Figure.3.3). The user needs to use these lock and unlock holograms to place or replace the main-menu in the room anywhere he wants. The lock and unlock holograms are changing colors due to their functions to make it clear if the home is locked or unlocked. If the lock is red, that means the home is locked and not movable. If the lock is green, the home is unlocked and movable.

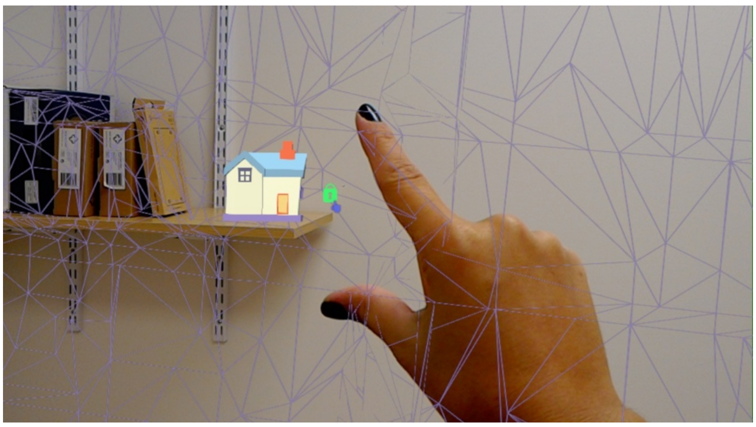


Figure 3.3 : The main-menu button with move/stop button.

Build button opens the first sub-menu consisting of four primitives to help the user block unwanted objects in the real world or build new objects in the space (Figure.3.4).

For instance, if the user is sensitive to lights, he can block them with a primitive object that fits the shape of the light. Or if the user wants to change the color of the walls, he can modify a cube primitive to fit the shape of the wall and change the color of the primitive.

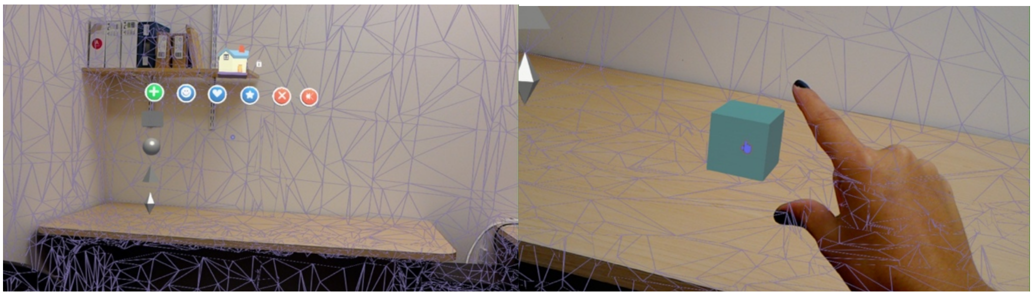


Figure 3.4 : Build menu with sub-menu objects.

Laugh button enables the second sub-menu with four mood buttons (Figure.3.5). Mood options are rain, snow, star rain, and heart rain. The current mood options are placed to give the idea of the mood sub-menu. All of them are customizable and can be changed.

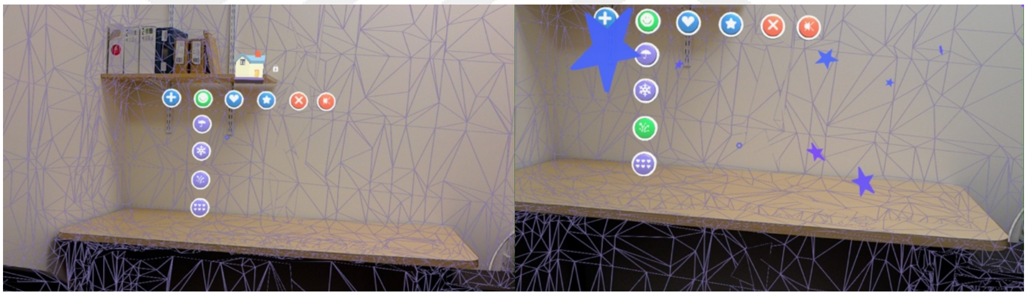


Figure 3.5 : Laugh menu with sub-menu objects.

Live button shows four animals as in the shape of 3D cartoonish models imported from Unity Asset Store (Figure.3.6). The animal options are dog, cat, turtle, and bird. They are chosen considering the domestic animals, nevertheless they can also be customized according to user choices.

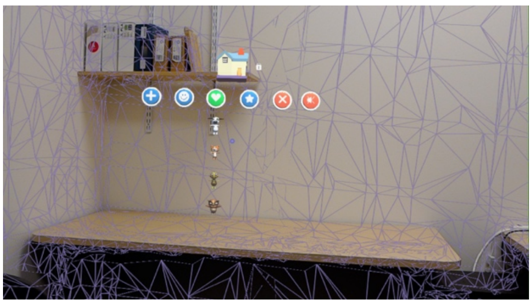


Figure 3.6 : Live menu with sub-menu objects.

Favorites button displays the last sub-menu with the favorite places or objects (Figure.3.7). Favorite places are predesigned virtual or saved real rooms. They can be integrated to the user`s surroundings. The current 3D models in this sub-menu are placeholders. They are completely customizable holograms. It is suggested that these places can also be created using the holograms available within the interface. Favorite objects present the personal objects of the user that can calm him.

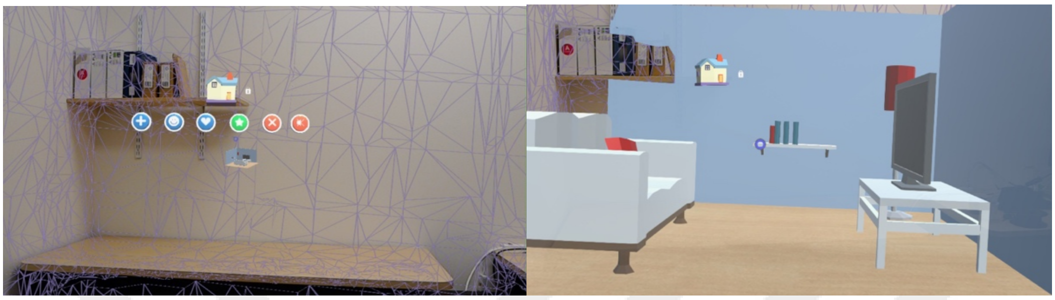


Figure 3.7 : Favorites menu with sub-menu objects.

Delete button enables erase function (Figure.3.8). When it is activated, the delete holograms attached to each object in the scene appear, and the user can remove the objects he wants to.

Figure 3.8 : Delete button in action.

Mute button allows user to turn off the sound in the interface (Figure.3.9).

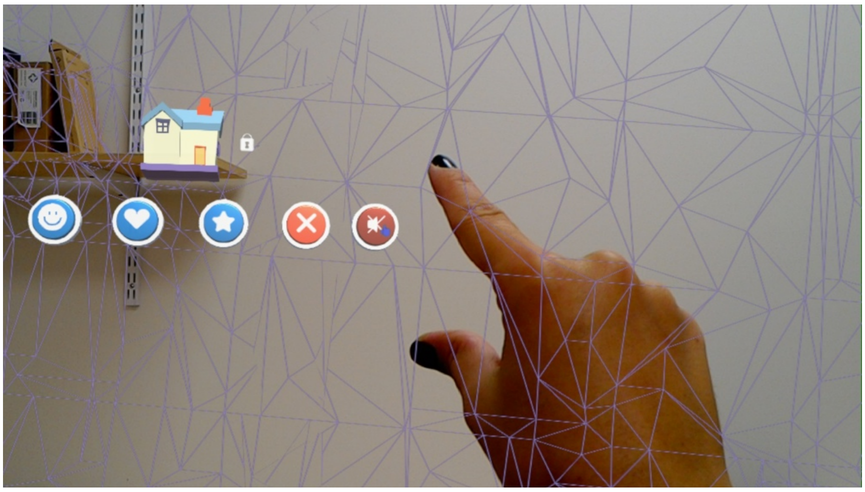


Figure 3.9 : Mute button in action.

3.1.2 Interaction Design

The interactions are designed with available interaction features of the HoloLens device considering the guidelines of interaction design for people on ASD (Hussain, Abdullah, Husni, & Mkpojiogu, 2016).

The user experience flow starts with opening the application in which the My Ho Me is already integrated. At first the main-menu button should be placed in the surrounding of the user. Secondly, a category from the main-menu should be chosen, then a hologram needs to be selected from the sub-menu of the chosen category. If the user wants to exit the interface, then the main-menu button needs to be closed.

Users can choose the objects/holograms they wanted to add to the room from the sub-menus. When the object/hologram is placed in a 3D environment, its coordinates are measured and locked by HoloLens. So, these objects are called "World-locked contents". That means even the user walk through the place, the objects/holograms will remain in the same spots where the user puts first.

Hand gestures are one of the main reasons why the HoloLens device is selected for this study. Interacting with an interface via hand movements is assumed as a natural interaction. Thus, there is no need to learn how to use the device, and users do not need to think hard what to do with the buttons or objects they see in the interface. There is also voice input available for HoloLens. Nevertheless, since most autistic people may have problems with voice communication (Smith, Goddard, & Fluck, 2004), voice commands are not used for the interaction design.

In My Ho Me, three hand gestures are used that are accessible for HoloLens: bloom, air tap, and tap and hold (Figure.3.10).

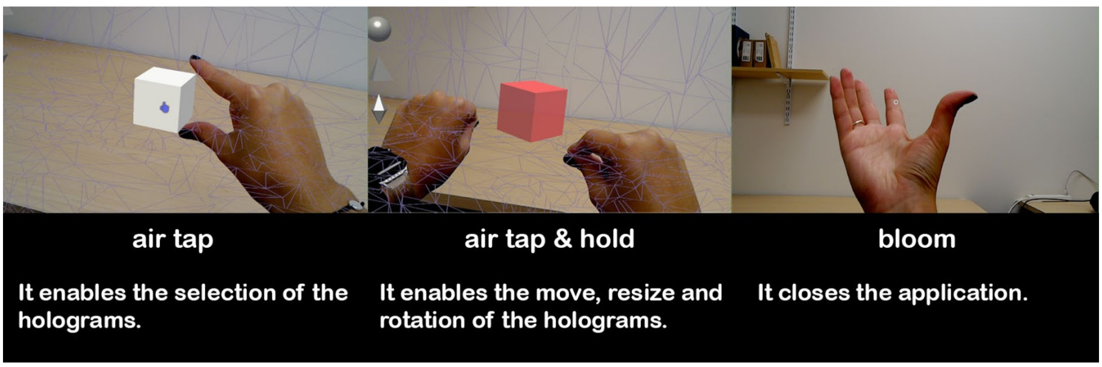


Figure 3.10 : Hand gestures.

3.1.2.1 Feedback mechanisms

Sound: Each button has a sound feedback, when they are activated. Every animal has a unique sound effect to make the user feel like they are alive. Also, each sub-menu items of the laugh menu plays unique sound effects to demonstrate the ambiance. Moreover, when an object is instantiated in the scene, it also comes with a sound to get the attention of the user.

Cursor: The shape of the cursor is changing from circle to hand ready, when it detects the user`s finger (Figure.3.11).

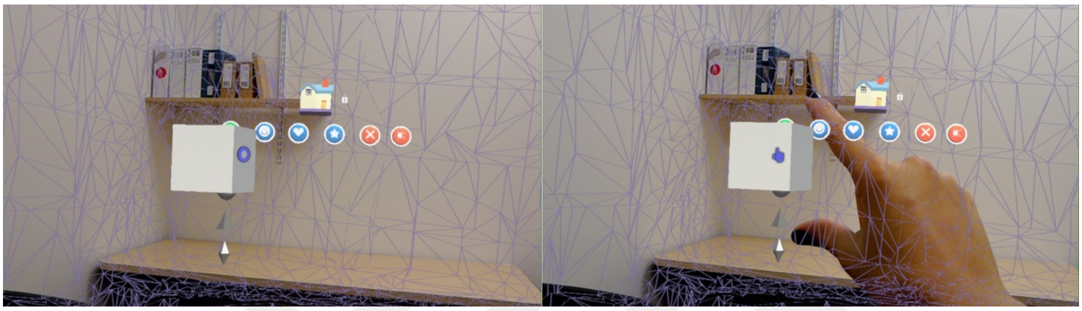


Figure 3.11 : Cursor feedback with changing icons.

The light appears around the cursor when it detects a virtual surface (Figure.3.12).

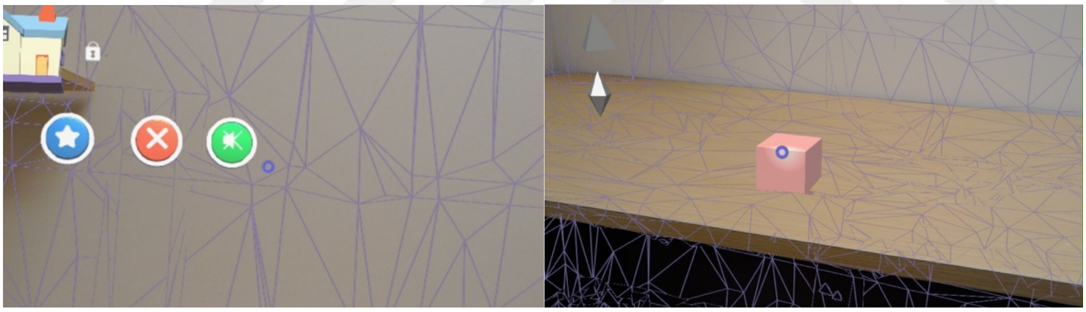


Figure 3.12 : Cursor feedback with light.

Animations: Each instantiated animal comes with an animation. Although the animals in the sub-menu are still, the instantiated animals are moving all the time.

Movement: When the toggle-buttons are tapped on, they are moving to perform the pressed button action. And all the objects that are instantiated in the scene moves, when they are tapped on. In that way, the user can separate the objects that functions as button and the objects that are present and interactable in the scene.

3.1.2.2 Button function list

Button functions can be studied in six parts. First part is the landing scene of the interface (Table.3.1). Main-menu is the second part with six toggle-buttons

(Table.3.2). In the other parts, sub-menu functions can be explained in detail (Table.3.3, Table.3.4, Table.3.5, Table.3.6).

Table 3.1 : Landing scene button functions.

	**Main-menu button:** First menu in the chain, contains all categories and holograms. **Gesture type:** Air tap. **Sound:** Yes.
	**Move/Unlock:** It shows the home locked. **Gesture type:** Air tap / Left: still version (inactive), Right: on gaze. **Sound:** Yes.
	**Stop/Lock:** It shows the home unlocked. **Gesture type:** Air tap / Left: still version (inactive), Right: on gaze. **Sound:** Yes.

Table 3.2 : Main-menu button actions.

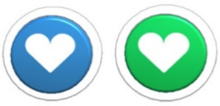
	**Build:** It contains primitives necessary to build. **Gesture type:** Air tap / Left: still version (inactive), Right: tapped (active). **Sound:** Yes.
	**Laugh:** It provides four mood options. **Gesture type:** Air tap / Left: still version (inactive), Right: tapped (active). **Sound:** Yes.
	**Live:** It contains 3D models of four animals. **Gesture type:** Air tap / Left: still version (inactive), Right: tapped (active). **Sound:** Yes.
	**Favorites:** Favorite places and objects can be saved and found here. **Gesture type:** Air tap / Left: still version (inactive), Right: tapped (active). **Sound:** Yes.
	**Delete:** It activates the delete icons on the objects present in the scene. **Gesture type:** Air tap / Left: still version (inactive), Right: tapped (active). **Sound:** Yes (only for activation).
	**Mute:** It mutes all sounds in the scene. **Gesture type:** Air tap / Left: still version (inactive), Right: tapped (active). **Sound:** Yes (only for unmute action).

Table 3.3 : Build menu actions.

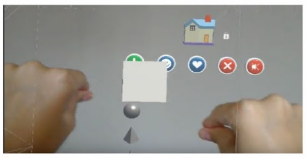
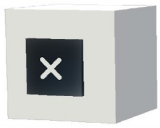
	In the menu, there are four primitives to use. Each primitive can be instantiated for many times. Gesture type: Air tap. Sound: Yes.
	There are seven color options for each the primitive. Gesture type: Air tap. Sound: No.
	Each primitive can be moved and resized. Gesture type: Air tap and hold. Sound: No.
	When the delete button is activated, a delete icon appears in front of the primitives present in the scene. Gesture type: Air tap. Sound: Yes.

Table 3.4 : Laugh menu actions.

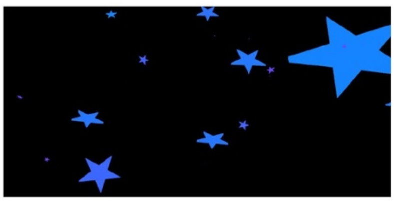
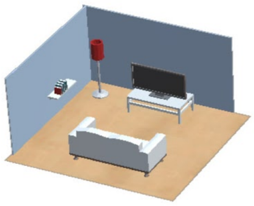
	In the laugh menu, there are four moods to choose. They can be activated at the same time. Gesture type: Air tap. Up: still version (inactive), down: tapped (active). Sound: No.
	Each mood contains different particle system like stars, hearts, rain, and snow with sound effects. They can only be activated by tapping on their buttons.

Table 3.5 : Live menu actions.

	In the live menu, there are four animals. Each animal can be instantiated for many times. Gesture type: Air tap. Sound: Yes.
	Each animal plays unique sound when it is tapped. Gesture type: Air tap. They can be moved and resized. Gesture type: Air tap and hold. Sound: No.
	When the delete button is activated, a delete icon appears in front of the animals present in the scene. Gesture type: Air tap. Sound: Yes.

Table 3.6 : Favorites menu actions.

	Many scenes, locations and objects can be added. The elements in the menu can be instantiated for many times. **Gesture type:** Air tap. **Sound:** Yes. They can formed into the physical place by being moved and resized. **Gesture type:** Air tap and hold.

The My Ho Me is developed for HoloLens holographic device which has the AR capabilities but more. Hence, the experiences in HoloLens can be more immersive than the typical AR devices like mobile phones. But today in 2018, not all the apps for HoloLens is using the whole features of the device has, so they might be experienced more like in AR (Figure.3.13).

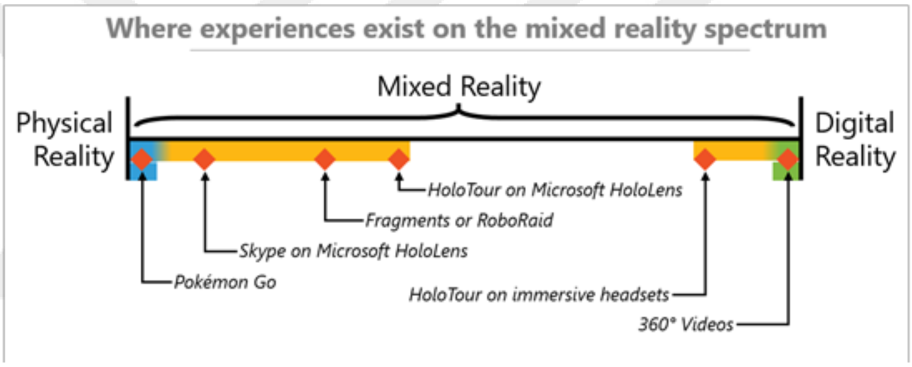


Figure 3.13 : Mixed Reality Spectrum with HoloLens applications (URL-21).

The proposed spatial interface in this study is defined as an MR interface, and it is assumed to be located between the Fragments, RoboRaid and HoloTour applications on the mixed reality spectrum (Figure.3.13). The figures below present the MR characteristics of My Ho Me interface to show both AR and AV capabilities.

The holograms in the interface can recognize the space and interact with them (Figure.3.14). In Figure.3.14 while the red cube can be experienced in the real world, the physical table is also present in the virtual world of the red cube. Therefore, the cube collides with the table. Also, in Figure.3.14 the star particles can detect the elements in the physical room, so they bounce when they hit the real wall, floor, or table. That means the virtual elements and the physical elements are sharing a common space. In Figure.3.15 the fire alarm in the room is blocked with opaque holograms. If the user keeps adding holograms into the real world, the physical world will turn into a hybrid space with full of virtual elements (Figure.3.16, Figure.3.17) To sum up, My Ho Me interface can be used for both as an AR app just to place some virtual content in the physical space, and also as an AV app to turn the physical place into a mixed place with full of virtual content. And this virtuality can affect the perception of the user through the real space.

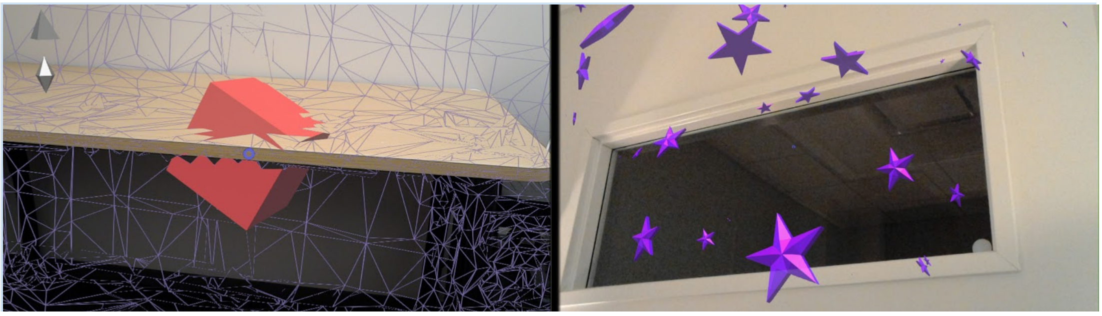


Figure 3.14 : Left: Red cube collides with the table. Right: Particles collide with the space.

Figure 3.15 : The fire alarm is blocked by a cube.

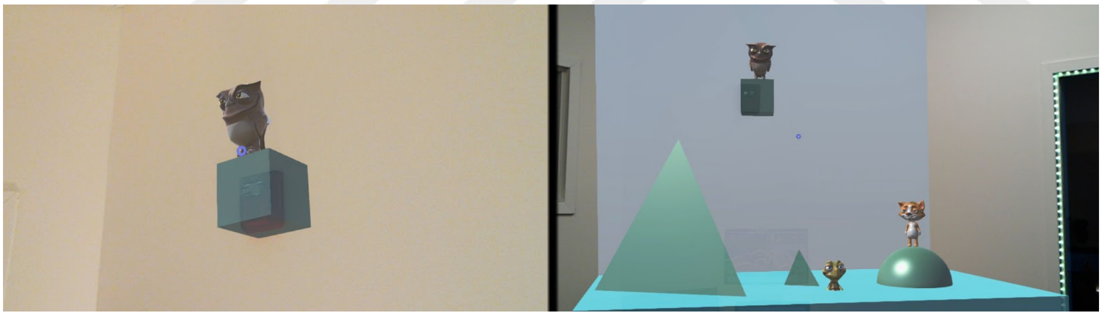


Figure 3.16 : More holograms are added to the physical space.

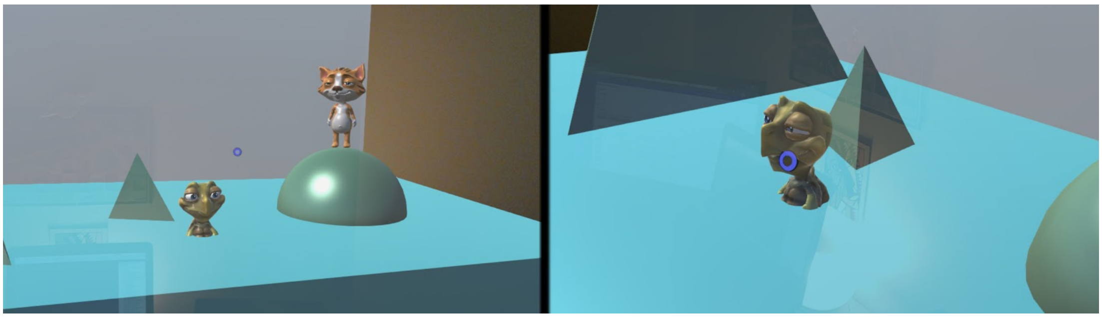


Figure 3.17 : The perception of the real space with virtual elements.

3.2 Development

There are some system requirements to develop for HoloLens, so the features of the laptop which is used for this study are:

- 64-bit operating system
- Windows 10 Pro
- Visual Studio 2017
- 16GB RAM
- DirectX 12

The interface is designed in Unity Game Engine version 2017.4.1f1. This version is recommended for HoloLens development during the time of the development process in the first half of the year 2018.

In the beginning, MixedRealityToolkit-Unity package is downloaded from GitHub and imported into the Unity project. This package contains a toolkit necessary for HoloLens and other MR gadgets development. The capabilities of devices are listed in the player settings. The capabilities enabled for this project are InternetClientServer, PrivateNetworkClientServer and Spatial Perception. Spatial Perception is critical for Spatial Mapping feature of the HoloLens. Also, Spatial Mapping asset from the toolkit should also be added to the project along with the Input Manager for gaze and gesture settings. The distance to the nearest visible object is suggested as 85 cm, but during the development process, it is changed to 10 cm to give the sense of touching the holograms to the user.

Some basic scripts are used and modified for each component in the interface (App.A, Figure.3.18, Table.3.7).

SceneContentAdjuster: In the development process, the interface elements are combined in one object called “Scene Content” to be able to add the SceneContentAdjuster (Figure.3.19). It is a code to align all scene content with the height of the user. Since all objects in the scene are connected with a button logic, they are all layered in the scene under the first object “menu”.

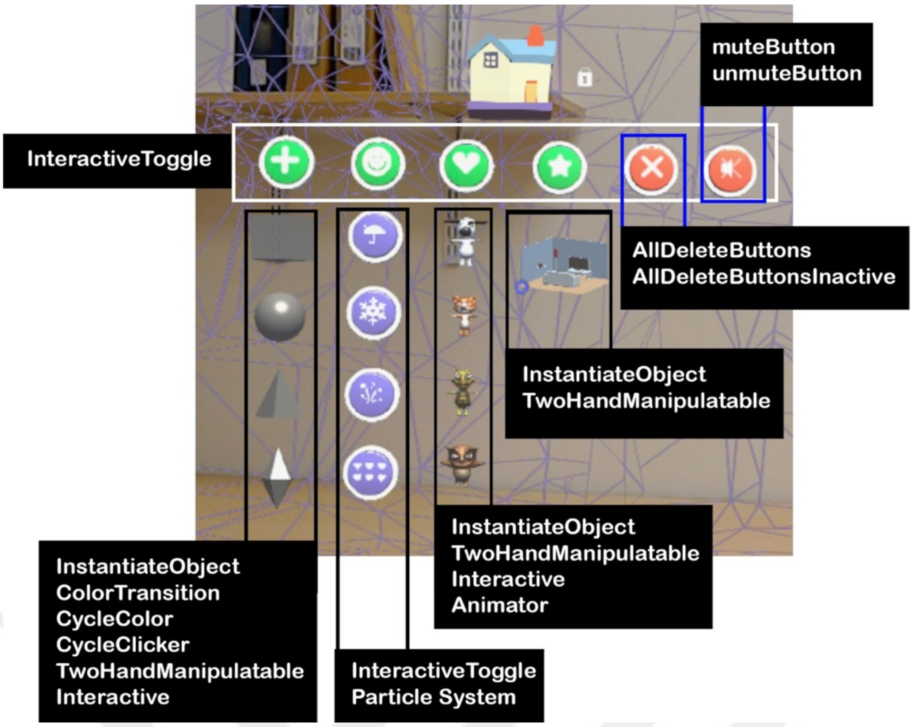


Figure 3.18 : Main scripts used for each component in the interface.

Table 3.7 : Key interaction scripts.

InstantiateObject	This script enables creating new objects in the scene by air tap.
ColorTransition, CycleColor, CycleClicker	It enables user to change the color of the primitives by air tap.
TwoHandManipulatable	It allows the move, rotation and scale by air tap and hold.
Animator	It enables animation and sound feedback when the user tap on the object it is attached. Each 3D animal model has the animator which provides unique animation.
Interactive	It attaches the voice feedback component to the object and enables 3D models to be able to function like a button.
AllDeleteButtons	It makes all delete icons hidden in the objects appear in the scene. Users can tap on the icons on the objects which they want to remove from the scene.
AllDeleteButtonsInactive	It deactivates the delete button. Thus, all delete icons disappear in the scene.
muteButton	It mutes all the sounds in the interface.
unmuteButton	If the muteButton script is running, the unmuteButton script is used to unmute and play all the sounds in the interface as usual.

MoveWithObject: Menu object contains main-menu button, move and stop holograms. MoveWithObject script is attached to the menu object to follow the user head movement (Figure.3.19). In that way, if the user unlocks the home, the menu moves with the user.

Figure 3.19 : SceneContentAdjuster and MoveWithObject scripts (App.A).

InteractiveToggle: All buttons on the main-menu have the InteractiveToggle script to remain pushed when the user taps on them and to be released when the user tap on them for the second time (Figure.3.20). Mood options are also working as toggle-buttons to allow easy on and off system. The user can activate all the particles at the same time and mix them.

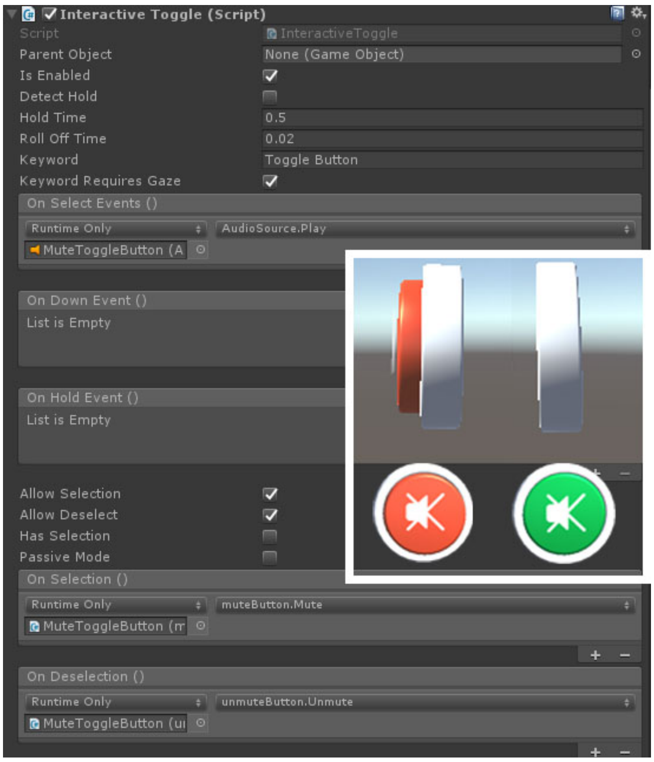


Figure 3.20 : InteractiveToggle script view on Unity.

Under the build button, there are four primitives with the script “InstantiateObject” attached. This script enables creating new primitives in the scene. Each primitive has “ColorTransition”, “CycleColor”, and “CycleClicker” scripts; thus, users can change the colors of them by air tap. There is also “TwoHandManipulatable” script on them to allow the move, rotation and scale by air tap and hold.

Mood button also has four sub-menu elements including four mood options. These mood options are also working as toggle-buttons to allow easy on and off system. Each mood option has “InteractiveToggle” script to be able to activate particle type attached. Rainy mood has rain particles, the snowy mood has snow particles, heart rain mood has many hearts particle, and fireworks mood has starts particle. The user can activate all the particles at the same time and mix them. Alternatively, they can deactivate the ones they want to close by pushing their buttons.

Four animals are placed under the animals' button with the script “InstantiateObject” attached as in the same logic with the category “build”. So, when the user taps on an animal, that animal is instantiated in front of the user. “Interactive” script and an animator are attached to each animal to enable animation and sound feedback when the user tap on. Each animal has unique animation and voice related to its type. Again, there is “TwoHandManipulatable” script on them to allow the move, rotation, and scale by air tap and hold.

Place button contains only one sample room to show the possibilities of the interface. It works similar to other elements in the interface. The user can instantiate the room by tapping on it, and move, rotate and resize it by air tap and hold gesture.

When the delete button is activated, it means “AllDeleteButtons” script is running, and all delete icons hide in the objects appear on the holograms in the scene. Users can tap on the icons they want to remove from the scene. After the deletion process is completed, the user can deactivate the delete button by tapping on it again to run “AllDeleteButtonsInactive” script. So, the delete icons disappear.

Mute button has two scripts attached: muteButton and unmuteButton. When it is activated, “muteButton” script is running and all the sounds in the interface is muted. Also, when it is deactivated, “unmuteButton” script is running, and the sounds are working as usual.

3.3 Iterations and Prototyping

There have been some changes are made during the design and development process. In the first design phase, besides the main-menu button and move/stop button, there was a direction indicator in the scene showing where the home is, but then it is removed to make the scene simpler. And the main-menu was consisted of blockers, objects, and spaces with white icons and labels on a transparent rectangle button and placed vertically on the view (Figure.3.21).

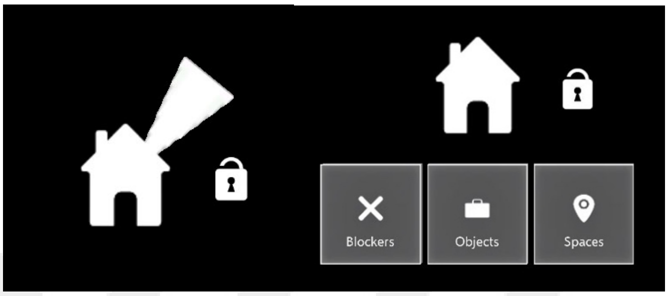


Figure 3.21 : The first version of the main-menu.

In the second design phase, the white home hologram button is changed into a colorful 3D home model, and the white cursor is replaced with a colorful cursor (Figure.3.22). Moreover, an object detection function is added to the cursor. In this way, the shape of the cursor is changing from a circle to the blurry point when the user aims it on an interactable object or not. During the categorization of the main-menu, animals are taken from the objects menu out and created as a separate category under the animals' button. In that way, the user can recognize the live holograms easily (Figure.3.23).

Figure 3.22 : The colored main-menu button and the cursor.

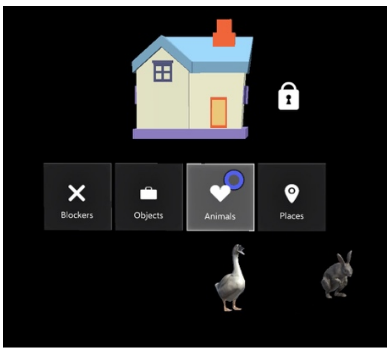


Figure 3.23 : Animal menu is created as a separate category.

In the third phase, the home-menu is reconsidered. Blockers and objects buttons are combined under the "Build" button. Moods button which contains effects like rain and snow is added to the menu along with the delete button which enables the remove option for the objects created in the scene (Figure.3.24).

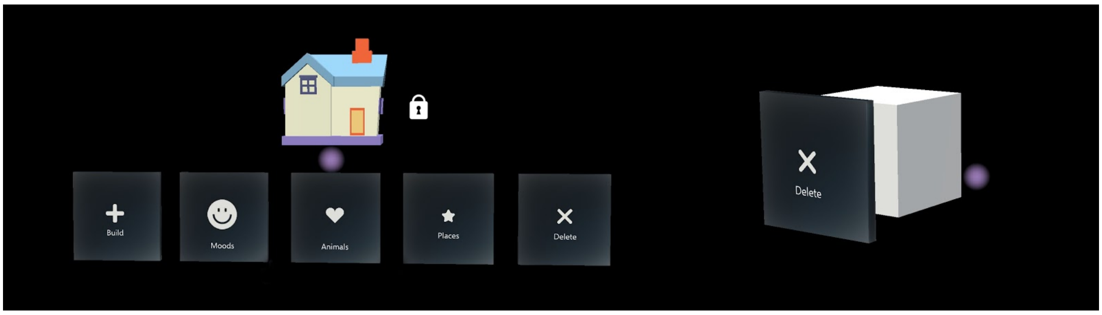


Figure 3.24 : Categorization of the main-menu.

In the fourth phase, all name tags of the buttons are removed because the autistic people tend to communicate better with visuals. Hence, starting from this phase the interface can be called as graphical user interface. All transparent button shapes replaced with colorful circle shaped 3D toggle buttons. So, the user can focus the button quickly, and experience the pushing action like it is real (Figure.3.25). When the user aims the cursor on a button, the button is highlighted in order to give feedback to the user. The icons on the buttons match with their contents.

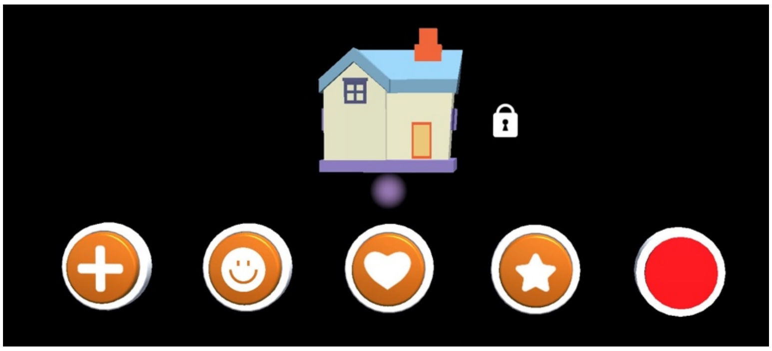


Figure 3.25 : The second version of the main-menu.

In the last phase, a mute button is added to the main-menu to mute all sounds in the interface. Sounds can also be disturbing for some autistic people, so it needs to be considered. Since the actions of build, mood, animals, and places buttons are different from delete and mute buttons, the colors of the first four buttons are changed (Figure.3.26). And also, the name of the first four buttons are changed even though there is no text in the interface. It is considered that the text can be used in the future. The new button names are: Build, laugh, live and favorites. The content list in each button was first placed vertically, but it causes a user experience problem. The user cannot activate all buttons at the same time and thus cannot see all the holograms together. So, in this phase, the hologram lists are replaced vertically to provide a better user experience (Figure.3.27).

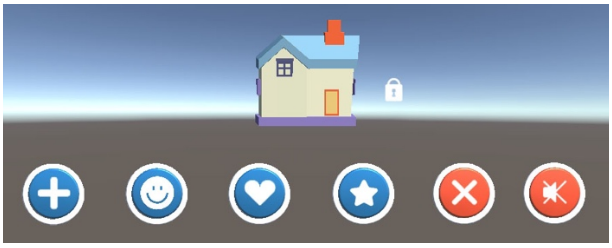


Figure 3.26 : Color differences of the buttons in the main-menu.

Figure 3.27 : The placement of the sub-menus.

After the interface is mostly formed, there have been some adjustments made for the pilot study with autistic children. The changes are made considering constraints like the unfamiliarity of the HoloLens device in Turkey and short trial duration for each participant. Thus, only two holograms from three categories are placed in the scene horizontally to reduce the learning time that is needed to get to know the interface completely (Figure.3.28).

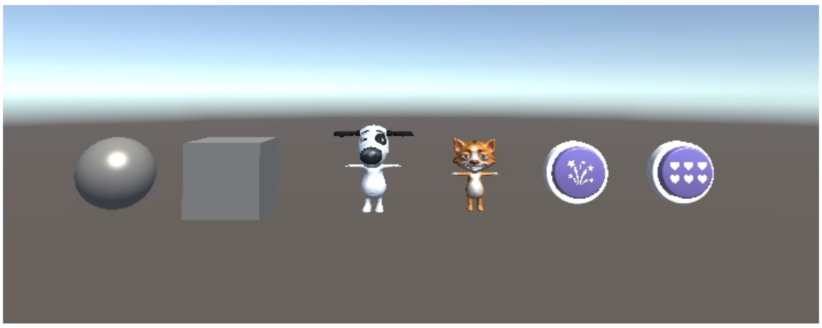


Figure 3.28 : The sample interface is created for the pilot study.

Two versions of the interface with and without mute button have been prepared in case there are sound sensitive subjects. Nevertheless, all subjects have used the interface without the mute button.

After six participants initially tested the interface, the professionals in the institution informed that the surface mesh behind the scene may cause focus problems. Therefore, it is removed from the spatial mapping component for the further experiments. Also, a reset button is added to the scene to reset the scene easily in-between user trials (Figure.3.29). In the end, the prototype is released as x86 architecture on the personal HoloLens device used for this study under the name of “My Ho Me”. All the scripts and data are available on the GitHub and the website www.my-ho-me.org.

Figure 3.29 : The sample interface is created for the pilot study with the scene reset button.

3.4 Evaluation

The evaluation process is organized in two parts: the expert-based evaluation, and the pilot study. In the expert-based evaluation, cognitive walkthrough and heuristic evaluation methods are used to evaluate and improve the prototype. Cognitive walkthrough (Table.3.8) is used to understand the perspective of the users by acting like one of them (Dix, Finlay, Abowd, & Beale, 2003; Galitz, 2002; Polson, Lewis, Rieman, & Wharton, 1992). Then for the heuristic evaluation, the features of the interface are compared with the eight golden rules by Shneiderman (Table.3.9), the usability principles by Nielsen (Table.3.9) and the interface recommendations for people with ASD by Pavlov (2014). Both cognitive walkthrough and heuristic method is evaluated the same interface which is the completed prototype, in the end of the study. The pilot study (App.B) is conducted to measure the reaction of the user towards to the HoloLens device along with the prototype of the intended interface. The interface used in usability testing evaluation is different than the other, consisting of less interface elements.

3.4.1 Methods to evaluate and improve the Prototype

3.4.1.1 Cognitive walkthrough

A scenario is prepared for the cognitive walkthrough. Based on the cognitive walkthrough method described by Polson, Lewis, Rieman, & Wharton (1992), goal, the task and sequence of actions are determined for the scenario (Table.3.8). And for each action, four questions are answered to analyze the interaction between the user and the interface (Dix, Finlay, Abowd, & Beale, 2003; Galitz, 2002). The completed interface is evaluated in this method and the user is assumed to be autistic with SPD and familiar to the prototype.

Table 3.8 : Goal, task and action sequence for cognitive walkthrough.

Scenario & Goal	Task	Action Sequence
Please block the two windows in the room.	Create blocks with cube primitives.	1. Locate the home-button. 2. Aim with gaze and tap on the home-button. 3. Locate build button. 4. Aim with gaze and tap on the build button. 5. Locate the cube primitive. 6. Aim with gaze and tap on the cube. 7. Move the cube and resize it to fit the first window shape. 8. Locate the cube primitive. 9. Aim with gaze and tap on the cube. 10. Move the cube and resize it to fit the second window shape.

Questions:

1. Is the action what the user is expecting to happen?

2. Is the action visible to the user?

3. Is the action recognizable?

4. Is the feedback of the action understandable?

Problems:

- The user may struggle finding the home-button, if he has forgotten where he puts it.
- The user should recognize the icon of the build button correctly.
- The cube can be rotated in each direction and degree, so it can be hard to fit it for 90 degrees window shapes.

- The user may want to copy the previous shape, but there is no copy and paste option.
- The user needs to recognize that there is no copy option and he should go to cube button and instantiate another cube.

The results of the cognitive walkthrough show that there are problems that need to be considered for the further development of the prototype. Some of the struggles with the interface were expected like the absence of the copy/paste function. And also, it was hard for the user to rotate the object without any rotation degree options. However, this feature was evaluated during the design process, but it was left off intentionally to make the interface simpler. Another problem is the need for locating the home-button after the first use. Since there was no indicator to show the location of the home-button, the user may have hard time to find it in the space. Moreover, it was not expected some visuals of the buttons might not have the same meaning for everyone. Because, it was the intention of the study to create an interface only with visuals.

The outcome of the cognitive walkthrough is reported within the open-source file along with the results of the other evaluations to inform the developers about the future development possibilities. A second alternative prototype with both visuals and texts options for the buttons is created. And it is noted that the degree-locking function can be added for the future versions, but it needs to be analyzed further.

3.4.1.2 Heuristic evaluation by comparing the interface with the guidelines

Although the Eight Golden Rules by Shneiderman (1997) and the usability principles by Nielsen (1993) are created for 2D interfaces, they are adapted to be used for the evaluation of a 3D interface in this study.

Table 3.9 : The evaluation of the interface compared to rules by Shneiderman (1997) and Nielsen (1993).

Rule	Evaluation
S1. Strive for consistency	✓
S2. Enable frequent users to use shortcuts	✓
S3. Offer informative feedback	✓
S4. Design dialog to yield closure	✓
S5. Offer simple error handling	✗
S6. Permit easy reversal of actions	✓
S7. Support internal locus of control	✓
S8. Reduce short-term memory load	✗
Eight Golden Rules by Shneiderman (1997).	
N1. Simple and natural dialogue	✓
N2. Speak the users' language	✓
N3. Minimize the users' memory load	✗
N4. Consistency	✓
N5. Feedback	✓
N6. Clearly marked exits	✓
N7. Shortcuts	✓
N8. Good error messages	✗
N9. Prevent errors	✗
N10. Help and documentation	✗
Usability principles by Nielsen (1993).	

S1, N4. Most of the actions require the same or similar interactions like the activation of buttons, instantiating of the objects. And the menu visuals are consistent with each other.

S2, N7. The main-menu button functions as a shortcut to open and close all the open menu and sub-menus.

S3, N5. Most of the actions provide feedback with sound, light, animation or movement.

S4, N1. Actions are grouped in main-menu and sub-menus. There is a hierarchy.

S5, N8, N9. . When the user makes an error while using the interface, there is no mechanism to handle and fix the error.

S6, N2. If the user instantiate an object by mistake, he can easily activate the delete button, which is a familiar action.

S7, N6. The user can move the menu and place it wherever he wants to. And he can close and open the menu whenever he needs to.

S8, N3. The interface is consisted of a main-menu and a four sub-menus. Thus, learning the all actions may take time for some people.

N10. There is no help button, or documentation inside the interface.

According to the heuristic evaluation made by comparing the interface features with the Eight Golden Rules by Shneiderman (1997), the proposed interface is fulfilled the six requirements out of eight (Figure.3.30). And according to the usability principles by Nielsen (1993), it is fulfilled the six requirements out of ten. The features that should be considered are:

- Need for the automated error correction system
- Need for the less menu-items or buttons
- Need for a help button or system

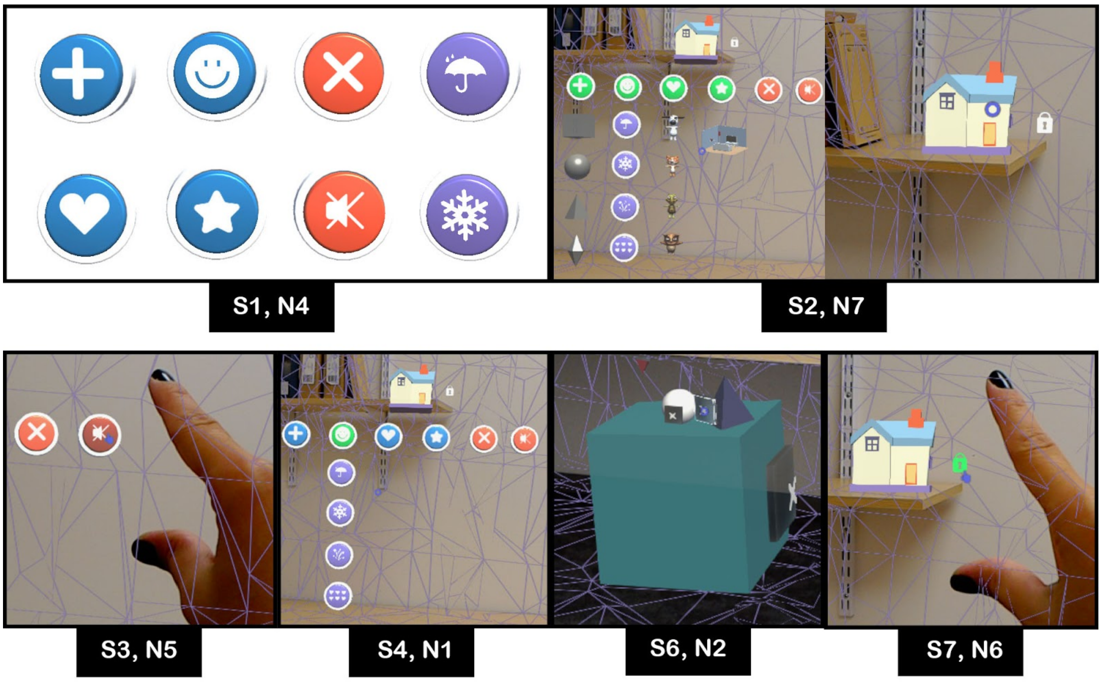


Figure 3.30 : Comparison of the guidelines with the prototype.

The interface characteristics is also evaluated in light of the interface recommendations for people with ASD by Pavlov (2014). Since these recommendations made for the websites and 2D interfaces, only presentation and interaction parts are considered in the evaluation (Table.3.10).

According to the comparison results, for the presentation part, five features out of ten are not measurable as they are related to text presentation. The proposed interface is fulfilled three requirements of the remaining five. And for the interaction part, it is fulfilled four requirements out of seven. The issues that need to be addressed are:

- The elements in the interfaces have mostly bright colors, not soft colors.
- The interface is consisted of visuals only, no text added.
- There is no instruction on how to use the interface.

After the expert-based evaluations are completed, the necessary changes are implemented to the prototype. The color scheme is changed, and the texts are added to the main-menu buttons. A help button is also added within the instructions on how to use the interface. Nevertheless, not all of the issues are resolved yet. Further research should be done to develop an error notice and management system, and also to shorten the memory load of the user.

Table 3.10 : Interface recommendations for people with ASD by Pavlov (2014).

Presentation		
Do:		
Use contrast between font and background	not measurable	
Use soft, mild colors	−	The color scheme of the interface is created mostly with vivid and fun colors. Soft and mild colors are not used everywhere.
Make sure text box is clearly separated from the rest	not measurable	
Present text in a single column	not measurable	
Use simple graphics	+	Simple graphics are used throughout the menu visuals.
Use clear, sans-serif fonts	not measurable	
Do not:		
use bright colors	−	Vivid colors are mostly preferred in the interface.
use background images	+	No background is used or available in the interface.
overlap transparent images and text	not measurable	
use pop-up elements and distractions	+	The main menu and sub-menus are simply designed on a grid system.
Interaction		
Do:		
Design for simplicity and few elements on screen	+	Interaction is provided with simple buttons annd 3D objects.
Try to have one toolbar	+	There is only one menu structure available.
Use clear, large buttons with both icons and text	−	Although the buttons are large and clear, no text is used.
Give short instructions of use at every step	−	There is no instructions available to the user.
Do not:		
use cluttered interface	+	The menu structure simple, placed in a grid system.
use many-colored icons	+	The button colors are mostly the same, they change only throughout main-menu and sub-menu.
use buttons with icons only	−	There is no text in the interface.

3.4.2 Pilot Study

It is a pilot study to observe the user behavior towards the interface of the prototype. Since there has not been found any published experiment report on the use of spatial interfaces by autistic people/children, the primary purpose of the test is determined as introducing the prototype of the spatial interface to autistic children, and so the task is defined as recognizing the elements in the interface and interacting with them appropriately.

The pilot study is performed in Bursa Doruk Special Education and Rehabilitation Center (Ozel Bursa Doruk Ozel Egitim ve Rehabilitasyon Merkezi) in Bursa, Turkey. Since the people with ASD have different abilities and disabilities, a consultancy is needed to choose the right participants for the test.

In total, twelve autistic children with different autism functioning levels between the ages, 6-16 are tested (Figure.3.31). It is noted that all participants were unfamiliar to the HoloLens before. Each participant used the device for a short time to see the objects in the interface and performance the gaze and air tap gestures for interactions. There are also two participants wearing their glasses while trying HoloLens.

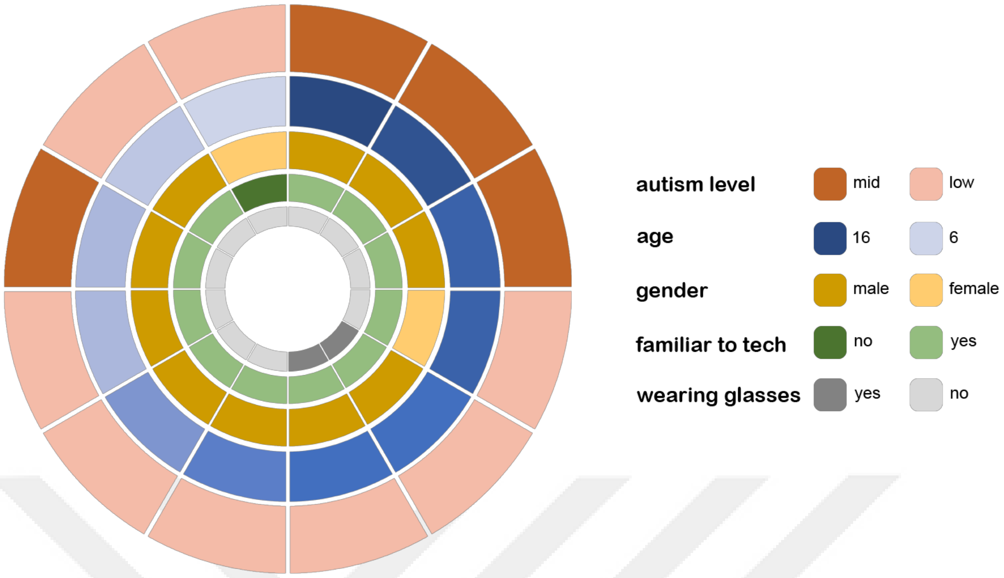


Figure 3.31 : Participants` profile.

The evaluation of the pilot study is formed by the interviews and observations during the experiment. The participants are told that the interface is a demo and they are observed as they are testing it for the first time. They are also encouraged to think aloud, and they played with the interface as individuals, not as a group.

The user perception on the interface is evaluated with two questions. The participants are asked if they want to use the device, and whether they like the interface layout. And then, the performance of users when they interact with the interface is measured based on three different data collected during the experiment: interaction accuracy, task completion time, and clarity of feedbacks. First, the screen-recordings and the observation between user changes are analysed to find out if the user interacted with the device and the interface correctly. Then, to measure the necessary duration to make the first contact with the device and the interface, the duration of the task completion is recorded. The task was recognizing the elements in the interface and interacting with them appropriately. And at last, the reaction of the participants is examined to determine if the feedbacks are understandable by the participants.

Throughout the experiment, the HoloLens is connected to the HoloLens Device Portal. In this way, the live camera view is made available to observe the user experience via screen-recording. Also, a Samsung 360-camera and an iPhone recorded the experiment. The scene states are noted before it is reset for the next user.

Setting: A classroom with a children chair placed in the middle of it. The computer and cameras are placed in the corner of the room. A couple of teachers were standing near the participant or across the room (Figure.3.32).

Figure 3.32 : Setting of the pilot study.

Equipment: HoloLens 2016 Developer Edition - Windows 10, Razer Blade 14" Gaming Laptop - Intel Core i7 - NVIDIA GeForce GTX 1060 - 16GB RAM - Windows 10 Pro - VR Ready, Samsung Gear 360-Camera, iPhone 8, notebook and pen.

The initial results and findings of the study is presented as follows.

4. RESULTS

The intention of the study was to provide an open-source spatial interface toolkit to be used in MR applications for autistic people with sensory difficulties. During the study, a spatial interface is designed, and the prototype is developed and evaluated. The interface is designed and developed based on the idea of Home Base intervention method. In the Home Base method, when the autistic people with SPD feels like s/he is about to have a meltdown because of the disturbing elements in his/her surrounding, s/he uses an area in a specific place that s/he uses everyday like school or work, to relax. The interface aims to provide the same calming effect of Home Base, but not in just specific places, in everywhere that s/he can access his/her HoloLens. After some iterations are made, the prototype is evaluated, and the results are explained below.

The expert-based evaluations are conducted with the cognitive walkthrough and heuristic evaluations which introduced some issues that users may have during the interaction with the interface. In addition, some design details that needs to be analyzed and developed further are addressed. The analysis shows the features and functions that needs to be discussed for the next version of the prototype as follows:

- Copy-paste function
- Location indicator for the home-button
- Use of text to support the visuals
- Color scheme change
- Automated error correction
- Instructions on how to use

In the pilot study, the data collected shows that most of the autistic kids (on average age is 10) are unfamiliar to the HoloLens device and mixed reality technologies. The analysis shows that, eleven participants out of twelve wanted to try HoloLens and eleven participants told that they liked the interface, as shown in Figure 4.1. One participant did not share his thoughts on the interface. Only one participant out of twelve hesitated to try the device. Other eleven participants were excited about the device and wanted to try it immediately.

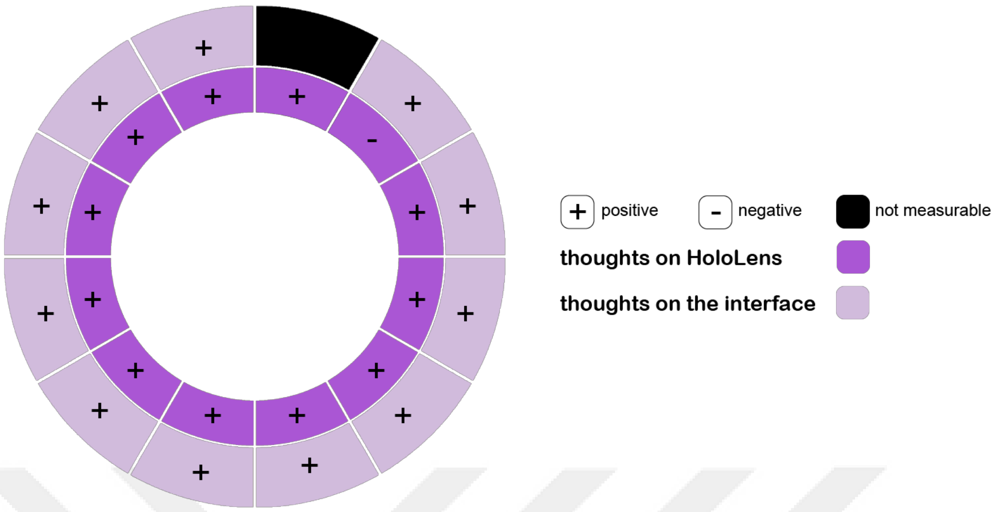


Figure 4.1 : The thoughts of the participants on HoloLens and the interface.

The interaction accuracy, task completion time and perception of the feedbacks are analysed and plotted on the graph, as shown in Figure 4.2. Based on the screen-recordings and our observation during the experiments, we determined that eight participants out of twelve were able to interact with the interface by using the hand gesture. And two participants from the remaining four were willing to interact. Nevertheless, they could not aim the cursor. Two participants did not try to use hand gestures, only watched the virtual objects as they stayed still in the scene. In addition, the average time to complete the task is 1 minute 27 seconds. Eight participants out of twelve completed the test in one minute, and two participants from the remaining four completed in 2 minutes. Only one participant could not complete the test because of the anxiety. The analysis of the clarity of the feedbacks shows that eight participants out of twelve understood the feedbacks. According to the interaction styles of four participants, sound feedback was more efficient and understandable. Nevertheless, the other four participants responded better when they recognized the button actions. One of the remaining four participants did not understand the feedbacks since he preferred to watch the virtual objects. The remaining three could not use the hand gestures, so the feedback effect is not measurable, as shown in Figure 4.2. As a limitation of the study, the learning curve for AR and MR gadgets for the participants cannot be measured in these circumstances, because there is only one HoloLens available and the device is not affordable for now in 2018.

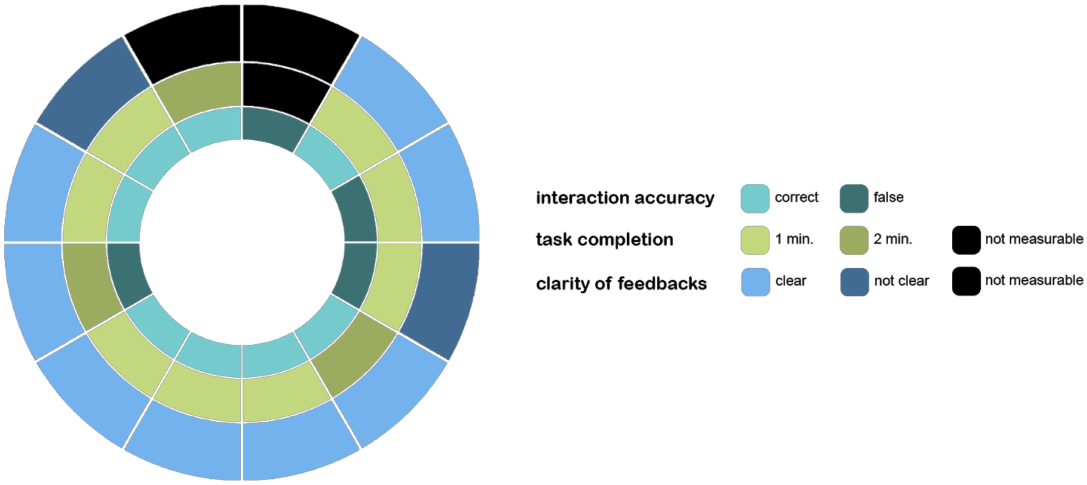


Figure 4.2 : The data collected from the pilot study.

5. DISCUSSION

The study provides an open-source toolkit for the autism application developers and indicates that the spatial interfaces developed using MR technologies can be an alternative for autistic people with SPD to draw their attention away from the disturbing situations in their surroundings. In this way, it is suggested that they can continue their daily lives, be focused on their work without any disruption and it can improve the quality of their life. Autism app developers can integrate My Ho Me interface into their apps, so the users can access it when they feel uncomfortable due to the disturbing elements or situations in their surroundings.

There are however some challenges determined within the study. In the pilot study, autistic children are able to use the HoloLens device and gestures easily. Nevertheless, it is still unknown that if most of the autistic people with SPD can benefit from the interface. More user testing is required for further development. Apart from that, all participants in the pilot study like the device. They imply that HoloLens is like a cool futuristic glass. But it is important to note that the device is heavy to wear for more than an hour and the field of view is limited to 35 degrees. This may lead to unanticipated user reactions.

There are also some problems detected during the cognitive walkthrough and heuristic evaluations. Even though some of these problems are fixed for the next version of the interface, auto correction system and copy-paste function are still open for development, which are relatively advanced functionalities and may require additional processing power and sensory technologies. A part of these inconsistencies may be related to the lack of the interface design guidelines in AR, VR, and MR environments. And since obsessions of the autistic people may widely vary, the interface could not be tested to cover all possibilities. Specific problems may come about for certain symptoms and reactions. Thus, developing a highly customizable interface for people with ASD may be a very beneficial solution. Besides, machine learning could be implemented to the interface and so the interface can gain ability to adapt to each user and improve itself over time.

My Ho Me is designed by using real world physical characteristics. It uses the light and shadows, so that the user can understand the objects are 3D. And some of the objects are placed in different angles to give the user the sense of depth. The interface is not limited to the users` field of view but limited to the real-world boundaries. The user can place the objects in real world, move through them, and interact with them naturally via hand gestures. Thus, My Ho Me interface still provides an opportunity for both autistic people and developers. It can increase the awareness of developers about the sensory problems of autistic people. And if it is applied today, even simple applications may show large benefit.

The user model of the study is specified as autistic people with SPD, but it should be noted that one of the three common symptoms of autism is also adaptation problem to the new environments (Schwenck & Freitag, 2014). So, the end product can also be useful for most of the autistic people that can have environmental adaptation problems.

Since it is mentioned in different studies that autistic people like using technological devices (Goldsmith & LeBlanc, 2004; Lofland, 2016; Diener, Wright, Wright, & Anderson, 2016; Fletcher-Watson, 2015), there are many applications on the market. The current apps offer mostly 2D interfaces and they are also difficult to use related to their interface designs (Hussain, Abdullah, Husni, Mkpojiogu, 2016). For the autistic people that have the sensory disorder, there are not any applications accessible that can allow modifying the space they are in. Hence, the proposed spatial interface is a different approach. AR-enabled mobile devices like smartphones and tablets require to interact with the 2D screen, they do not help the kids to get to know their environment and interact with the real world. With the help of MR, the autistic kids and people can recognize the places better, change the things they do not like and prevent the meltdowns related to sensory problems.

My Ho Me is formed by spatial interface elements that are ready to be integrated into the MR development projects. And this project provides the source code of the My Ho Me interface to all developers worldwide. In that way, it aims to encourage more people in the healthcare industry to create applications for autistic people with SPD in mixed reality technologies. The My Ho Me interface is just a start point to present how MR technologies can improve the lives of autistic people with SPD.

6. CONCLUSION AND FUTURE WORK

An open-source toolkit for spatial interface design and development is presented to be integrated into applications specific for autistic people with sensory processing disorder. The end product is a prototype and ready to import into a Mixed Reality application created by Unity Game development software.

In the study, before the first sketches of the interface design, a background study is conducted on autism spectrum disorder, software applications created for autistic people, mixed reality, and spatial interfaces. Thereupon, the first design outline of the interface is formed, and the prototype developed. The prototype iteratively improved upon personal code and design reviews. After that, the prototype is examined through the cognitive walkthrough and heuristic evaluation. A part of the interface is tested on twelve autistic children in a rehabilitation center located in Bursa, Turkey.

The results of the study suggest that wearable glass devices, such as Hololens, can be used by autistic people and spatial interface for autistic people with SPD is promising. Although there are still missing features determined through the evaluation process, this study can be used as a guideline for future work. Following the results, a new version of prototype is developed with addition of text to support visuals, help button to assist the user and customize the color scheme. The open-source toolkit can be accessed through the GitHub and the website www.my-ho-me.org.

It should be noted that designing spatial interfaces in MR for autistic people with SPD is cannot be constrained to solely to the findings and ideas used in this paper. There may be various other approaches that are more appropriate for some other demographics and the other user groups with distinct disability or syndromes. Computer software development evolves on endless iterations and comparisons and this study can only be considered as an early attempt to solve the problem.

Today in 2018, advanced technology is still not welcomed from everyone. That is because it is thought that someday all electronic devices will dominate the world. However, if the advanced technology is available today, at least it should be used for the best causes and developed accordingly. Mixed Reality technology is one of the advanced technologies available now, a tool to integrate virtual worlds into the real world. It can help many to expand their horizons, move from one place to another, to travel, to complete tasks remotely and communicate at a personal level worldwide. However, why is MR not part of people's daily lives even though it can be used for so many daily tasks?

Many workers are already using HoloLens every day in NASA, ThyssenKrupp, Ford, and ZF. It helps them to connect and collaborate with their colleagues and customers wherever they are and solve many problems. However, the device is still heavy and expensive for everyone to use. That is why augmented reality devices have the opportunity to become more popular than HoloLens right now. Having an AR-enabled iPhone or iPad is an affordable option to experience the AR in a way similar to the MR technology.

The AR technology that is known for years enables the virtual objects to be placed as layers in front of the user. However, ARKit and ARCore in some high-end devices have the technology to detect and map the 3D space of the user so that it can place virtual objects in specific coordinates in the real world. So, it can be said that today in 2018, it is not the AR that used to be known in the mixed reality spectrum. With the developing technologies, interaction types with the physical space are changing every day, and it is good to be able to adapt the changes and look for better solutions for everyone. A day may be close that many people use AR and MR technologies every day.

There are also hologram displays alternative to personal MR and AR devices. They can be used in many locations open to the public, especially in sensory rooms. Sensory rooms are places to focus and relax for people with special needs like autistic people with SPD. They are specially designed room to provide various sensory experiences. To equip those rooms with mixed reality technology can be an alternative solution for people who cannot afford personal MR devices.

As the years passed, the MR technologies can be improved with many other features like artificial intelligence. Microsoft is now working on AI and HoloLens integration in development mode. Right now, with the help of My Ho Me interface, users` favorite places can be saved to HoloLens and then saved places can be recalled in different locations, and new mixed spaces can be created. However, with the intelligent HoloLens devices, it can observe the space use behavior of the users and suggest the modification to the spaces accordingly or apply the changes automatically for the autistic people.

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APPENDICES

APPENDIX A

Scripts

More scripts are available at www.my-ho-me.org

- AllDeleteButtons:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
public class AllDeleteButtons : MonoBehaviour
{
   public GameObject[] objects;
   void Start()
   {
      objects = GameObject.FindGameObjectsWithTag("objects");
   }
  void Update()
   {
      objects = GameObject.FindGameObjectsWithTag("objects");
   }
   public void activateButtons()
   {
      foreach (GameObject shape in objects)
      {
         shape.transform.GetChild(0).gameObject.SetActive(true);
         Debug.Log("Sorry");
      }
   }
}
```

- AllDeleteButtonsInactive:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
public class AllDeleteButtonsInactive: MonoBehaviour
{
   public GameObject[] objects;
   void Start()
   {
        objects = GameObject.FindGameObjectsWithTag("objects");
   }
   void Update()
```

```
    {
        objects = GameObject.FindGameObjectsWithTag("objects");
    }


    public void deactivateButtons()
    {
        foreach (GameObject shape in objects)
        {
            shape.transform.GetChild(0).gameObject.SetActive(false);
            Debug.Log("Sorry");
        }
    }
}
```

- InstantiateObject:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
public class instatiateObject : MonoBehaviour {
    public GameObject element;
    void Start () {
            }
            void Update () {
            }
    public void spawnelement()
    {
     Instantiate(element, (Camera.main.transform.position) +        Camera.main.transform.forward,
curtain.transform.rotation);
    }
}
```

- muteButton:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;
using UnityEngine.SceneManagement;
public class muteButton : MonoBehaviour {
    public void Mute()
    {
            AudioListener.pause = true;
    }
}
```

- unmuteButton:

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;
using UnityEngine.SceneManagement;
public class unmuteButton : MonoBehaviour {
    public void Unmute()
    {
          AudioListener.pause = false;
    }
}
```

- SceneContentAdjuster (partial):

```
if (alignmentType == AlignmentType.AlignWithHeadHeight || alignmentType ==
AlignmentType.UsePresetXAndZWithHeadHeight)
        {
            contentPosition.x = containerObject.position.x;
            contentPosition.y = containerObject.position.y + CameraCache.Main.transform.position.y;
            contentPosition.z = containerObject.position.z;
           containerObject.position = contentPosition;
        }
```

- MoveWithObject (partial):

```
private void Awake()
      {
         if (ReferenceObject == null)
         {
            ReferenceObject = CameraCache.Main.gameObject;
         }
      }
…………………….

if (IsRunning)
        {
            Vector3 newDirection = ReferenceObject.transform.forward;
            if (KeepInFront)
            {
               if (KeepStartingOffset)
               {
                  newDirection = Vector3.Normalize(mOffsetRotation *
ReferenceObject.transform.forward);
               }
            }
            else
            {
               newDirection = mNormalzedOffsetDirection;
            }
```

APPENDIX B

Notes from Pilot Study

Subject I:

6 yrs - female - low-level communication problems, not so familiar to tech devices.

- She didn`t know the device.
- She wanted to try the device. She was shy and excited, tried the device three times consequently. In the second time, she got used to it. But then, she wanted to try it again for the third time.
- She liked it. During the third time, she started to explain the MR objects to her mother standing beside her.
- During the first try, she got excited to see the MR objects and removed the device immediately. During the second try, she saw the objects and tried to interact with them. During the third try, she started to talk about the objects as they are really in the room.
- 3 minutes. Gestures were not used.
- Not measurable.

Subject II:

8 yrs - male - low-level communication problems, familiar to tech devices, moves so much (like hyperactivity).

- He didn`t know the device.
- He wanted to try the device. Although he moves so much all the time, he stopped when he saw the device. He thinks the device is comfortable.
- He thinks it is easy to use and he liked it.
- Since he moves his head so much, he had difficulties aiming the cursor to MR objects. He tried to interact with them, but he couldn`t aim it.
- 3 minutes. Gestures are used, but not in a correct way. The aim of the cursor was not successful.
- When he heard a sound, he understood that he aimed the cursor on which object.

Subject III:

9 yrs - male - low-level communication problems, familiar to tech devices.

- He didn`t know the device.
- He wanted to try the device. He instantly started to use the device correctly.
- He liked the interface. During the experiment, he was so focused on using the device; he was smiling all the time.
- He made all the gestures, interacted so well with the device and the interface. He moved all MR objects and pressed all the effects and sound buttons. Thus,

he made many changes in the scene, organized them according to his imagination.
- 2 minutes.
- After he moved one object, he got the idea and interacted with all other objects in the same way.

Subject IV:

11 yrs - male - wears glasses - low-level communication problems, familiar to tech devices.

- He didn`t know the device.
- He wanted to try the device. He was excited. He thinks the device is comfortable.
- He liked the interface.
- He interacted with the MR objects, moved the primitives and made some changes in the scene.
- 2 minutes.
- When he touched an object, he heard a sound. So he kept trying the other objects to listen to their sounds.

Subject V:

12 yrs - female - low-level communication problems, familiar to tech devices.

- She didn`t know the device.
- She wanted to try the device. She was shy and excited. During the setup, she waited patiently and laughed when the device fitted hardly on her head because of her hair accessory.
- She liked the interface. At first, she didn`t believe that she can touch the MR objects. Then she tried to interact with them.
- She couldn`t success the hand gesture well enough, preferred to watch MR objects.
- 2 minutes.
- While she was trying the hand gesture, she accidentally moved some MR objects in the scene and thought she made a wrong thing. After that, she didn`t want to try to interact with them.

Subject VI:

16 yrs - male - mid-level communication problems, familiar to tech devices, best in mathematics.

- He didn`t know the device.
- He wanted to try the device. Although he has impatient behaviors in general, he waited for so long patiently during the setup.
- He is not able to express his thoughts and feelings. Even though he was nervous and excited, he wanted to see through the device without wearing it. And he didn`t want to give it back. He was curious about the device.
- He didn`t interact with the device and the interface.

- Not completed
- Not measurable

Subject VII:

11 yrs - male - wears glasses 09- low-level communication problems, familiar to tech devices.

- He didn`t know the device.
- He wanted to try the device, he was very interested with the look of the device.
- He was surprised when he first saw the virtual elements through the interface. He liked the interface.
- He interacted with the interface by hand gestures, liked the music coming from the virtual elements.
- 2 minutes.
- Since the virtual objects give feedback when the user touch them, he thought that the dog in the interface is running when he touched on it. So he behaved like it is alive, and asked if the dog can see him as well.

Subject VIII:

15 yrs - male - mid-level communication problems, familiar to tech devices.

- He didn`t know the device.
- Since he didn`t want to meet and communicate with a new person(me), he didn`t want to try the device.
- He liked the interface and seemed to be enjoyed the modified environment with the raining stars.
- He managed to use hand gesture and interact with the virtual objects.
- 2 minutes.
- The sound feedback was helpful for him, so he understood that he succeeded the hand gesture.

Subject IX:

7 yrs - male - low-level communication problems, familiar to tech devices.

- He didn`t know the device.
- He was so happy for being a subject for the experiment and wanted to try the device.
- He liked the interface.
- He interacted with the virtual objects by using hand gesture.
- 1 minute.
- He managed to do hand gesture but did not use it so much. He preferred to watch virtual objects.

Subject X:

12 yrs - male - mid-level communication problems, familiar to tech devices.

- He didn`t know the device.
- He was shy, but willing to try the device.
- He liked the virtual objects in the interface.
- He tried to interact by using hand gesture, but couldn`t succeed it.
- 1 minute.
- Not measurable

Subject XI:

10 yrs - male - low-level communication problems, familiar to tech devices.

- He didn`t know the device.
- He wanted to try the device.
- He liked the interface very much, he came back to try it again after his test was completed.
- He interacted with the interface by using hand gesture and also used volume up-down buttons on the device.
- 2 minutes.
- When he touched an object, he heard a sound. So he kept trying the other objects to listen to their sounds.

Subject XII:

8 yrs - male - mid-level communication problems, familiar to tech devices.

- He didn`t know the device.
- He wanted to try the device.
- He liked the interface.
- He interacted with the virtual objects by using hand gesture.
- 2 minutes.
- Since the virtual objects in the interface responds when the user touches them, the subject thought that he is really touching them.

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