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Augmented Reality E-Commerce: How the Technology Benefits People's Lives

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1. Introduction

In general, technology can benefit people's lives. For example, during the past 20 years, with the deveolpment of computer and Internet technology, e-commerce and online shopping have rapidly progressed, due to the convenience that they provide consumers. E-commerce websites, such as Amazon.com, Dell.com, and eBay.com, have become an integral part of many shoppers' lives.

However, according to most shoppers' experiences, e-commerce and online shopping are still not able to fully replace onsite shopping, especially for products like clothing, shoes, jewelry, and furniture. For many such products, onsite shopping has many distinct advantages over online shopping. One of the main advantages of onsite shopping is that it usually provides more direct interaction with the actual product. In contrast, conventional online shopping websites often cannot provide enough information about a product for the customer to make an informed decision before checkout. Onsite shoppers frequently engage in some sort of interaction with their potential purchase to discover the scent, texture, appearance, and/or sound characteristics of a product before buying it. Such experience is often impossible with current online purchases.

However, technology is progressing. In particular, Augmented Reality (AR), an emerging Human-Computer Interaction technology, which aims to mix or overlap computer-generated 2D or 3D virtual objects and other feedback with real world scenes, shows great potential for enhancing e-commerce systems. Unlike VR, which replaces the physical world, AR enhances physical reality by integrating virtual objects into the physical world. The virtual object becomes, in a sense, an equal part of the natural environment.

This chapter presents a new type of e-commerce system, AR e-commerce, which visually brings virtual products into real physical environments for user interaction. The new approach gives customers a chance to “try" a product at home or in another use environment. The chapter presents development of a prototype AR e-commerce system and a user study of the developed prototype. Experiment results and data both validate the new

AR e-commerce system and provide suggestions for improvement. Overall results of the study show that the AR e-commerce system can help customers make better purchasing decisions.

2. Background

2.1 VR in E-commerce

Virtual reality (VR) is a computer-simulated environment that allows users to manipulate 3D virtual models online. Recently, researchers have been using VR in e-commerce to provide consumers with a new type of shopping experience by interacting with virtual product models. Hughes et al (2002) presented an adaptive navigation support system for using a virtual environment for online shopping. Sanna et al. (2002) presented a VR e-commerce system based on VRML. They used QuickTime 3D to generate 360-degree image-based immersive backgrounds and an animated virtual human to help online shoppers navigate through their e-commerce environment. Bhatt (2004) analyzed the interactivity, immersion, and connectivity of several major VR-ecommerce websites, such as amazon.com, ebay.com, and schwab.com. Daugherty et al. (2005) conducted five experiments to study the usability of VR for e-commerce. Their results showed that users acquired more information about products when using a VR-based e-commerce system than when using traditional website tools. Fomenko (2006) developed a tool for creating online VR shops, which also gave domain experts more control during the website development process. With Fomenko's tool, developers can use high-level concepts to model and semi-automatically generate a complete VR shop.

2.2 Moving from VR to AR

Although prior studies show that VR can enhance e-commerce, by providing more product information through enhanced human-computer interaction, current VR methods for e-commerce still only provide scaled virtual product models displayed on traditional computer screens. New, more advanced, methods are needed to provide consumers with more realistic product models, with respect to size, customer experience, and user interaction.

AR is a technology which can mix or overlap computer-generated virtual objects with real-world scenes or objects. Unlike VR, which experientially replaces the physical world, AR enhances physical reality by integrating virtual objects into a physical scene. Generated virtual objects become, in a sense, an equal part of the natural environment.

In recent years, much research has focused on developing AR applications, which could be generally classified into two types, based upon the different devices used: optical see-through AR and video see-through AR. Optical see-though AR uses a semi-transparent screen onto which computer generated objects can be projected; users, can simultaneously view the computer generated images and see through the screen to view the natural background environment and, thus, see an integrated AR scene. Video see-through AR uses cameras to capture the live scene as a video stream. For each viewed image frame, a captured video image frame is processed and computer generated virtual objects are added. One advantage of video see-through AR is that the mixed scene can then be displayed on different devices. With video see-through AR, markers and computer vision methods are often used for tracking. Between the two prominent AR methods, video-based AR has attracted the most attention from researchers.

Although AR methods and applications have progressed significantly over recent years, there has been little research conducted related to using AR to enhance e-commerce. In 2001, Azuma et al. reviewed new advances in AR which, after 1997, included display devices and methods, indoor and outdoor tracking, model rendering, and interaction technologies. At that time, they identified several problems that still needed to be addressed, such as occlusion, broader sensing, advanced rendering, and user perception issues. In addition, in 2005, Swan et al's survey showed that, although there were an increasing number of AR applications, research which considered usability was only a small part (less than 8%) of the total, and most of the usability studies were neither formal nor systematic.

Among the limited number of prior related studies, Zhu et al. (2006) proposed AR in-store shopping assistant devices, which provided personalized advertising and dynamic contextualization. Their study was aimed at using AR technology to enhance in-store shopping. Zhang et al. (2000) proposed and developed a prototype direct marketing system that used AR technology. Salespeople could use the system to show the main features of a product by manually holding a plate with specially designed markers. With their marker-based system, they could mix a 3D virtual product with a real scene, videotape the resulting scene, and then send the video tape to interested customers by email. However, their method of using AR in e-commerce did not make full use of the advantages of AR. With their method, online shoppers had no direct interaction with either physical objects or virtual product models. With only video recordings of AR scenes, customers still might not know whether products are suitable for them in their real physical environments.

Two industry companies: metaio and bitmanagement (http://www.ar-live.de/main.php)(2007), are also trying to cooperate and extend e-commerce systems with AR technology. Users are asked to upload a photo of the personal environment with markers. The mixed scene can then be visualized through an online tool. With their application, online users can visually see how a model fits in their personal environment. However the static-picture approach greatly limits uses' direct interaction with virtual product models in a natural way, and their flexibility to try the virtual product in their environment.

In this study, a new AR e-commerce system was developed using, video see-through AR technology, since the devices needed for this type of AR system is more available to online consumers. Video see-through AR technology is also more flexible because the mixed AR scene can be displayed on different devices, rather than with a special optical see-through device only. The system integrates a full-sized virtual product model into an online shopper's physical environment and provides the customer methods for "realistically" interacting with the virtual product. With this system, online shoppers can directly and freely interact with the product model in their environment and in a more nature way. For example, they can physically move around in their environment to see how the product fits in their space from different viewpoints, and they can also move markers around in their environment to move the virtual products to different locations in their environment. This paper presents both the design of the AR e-commerce assistant system and related usability studies. Several key issues related to using AR to enhance e-commerce are also discussed and analyzed.

3. System and User Interface Design

In this study, an AR e-commerce assistant system was designed to provide consumers with more realistic product experiences and interactions. With the developed AR e-commerce assistant, online consumers can bring a product into their physical environment and even try out and visualize the product in their physical environment while shopping from their computers.

3.1 Structure

Like traditional e-commerce systems, our AR e-commerce system uses the Internet as the primary user interaction platform. However, with our AR e-commerce system, a video camera is needed to capture the consumer's physical environment and then integrate it with virtual objects in real time.
The system was developed as an Active X plug-in for an e-commerce web page. Online users can use web page navigation to search for and view pictures and product related information, just as they would with a traditional e-commerce website. However, online shoppers can also use the plug-in to bring virtual products into their physical environment and then interact with the products to determine if the products are suitable.
The client-server plug-in was made using the MFC and OpenGL libraries. The plug-in works between clients and an e-commerce assistant server through an Internet Explorer interface, so that online consumers can easily log onto the Internet, using different hardware, like a computer, cell phone, or Personal Digital Assistant (PDA), to access the server as shown in Figure 1. In this system, an extra video camera is needed, so that consumers can bring product models into their home, auto, outdoor, or other scenes. ARToolkit (Kato and Billinghurst, 1999) was used for tracking, and Open VRML was used for rendering models. The complete structure of the system is shown in Figure 2.

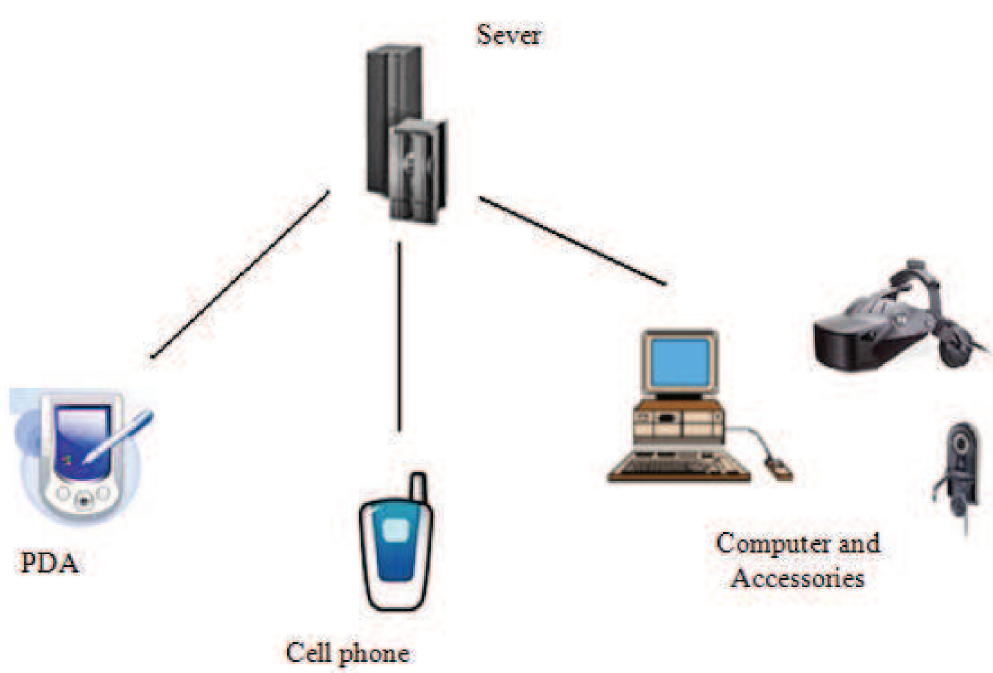


Fig. 1. AR e-commerce assistant system working model

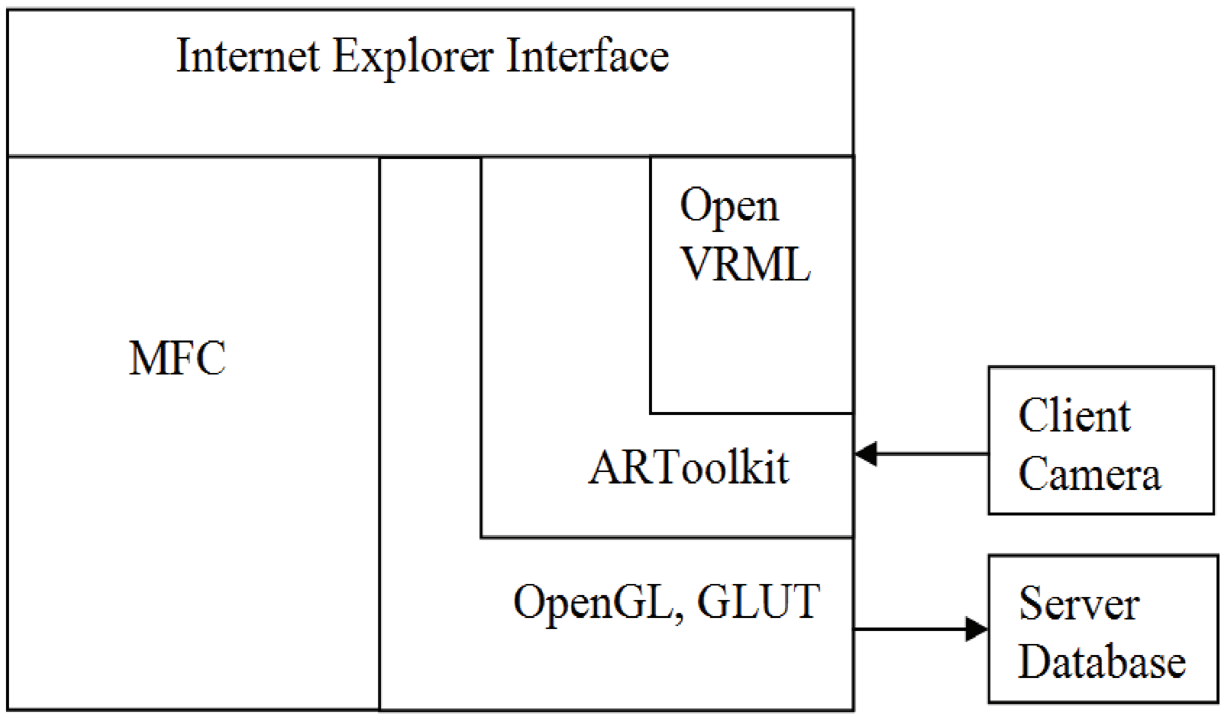


Fig. 2. The structure of the AR e-commerce assistant system

3.2 Interfaces

Primary users of the system are expected to be common computer users, with minimal computer experience. As a result, the user interface of the system was made as simple and user-friendly as possible. In the study, according to our analysis, we determined that consumer shopping typically includes three main tasks:

1. Searching for products.
2. Interacting with products.
3. Acquiring product information.

As a result, the user interface was designed to facilitate the three primary shopping tasks. The three tasks were combined into a two-level menu system within the AR window as shown in Figure 3. A 2D menu system was used, since it is still the most intuitive interaction method for computer users, due to their previous computer experience. Through the menu, users can access the full interaction capability which was designed for AR e-commerce. Shortcut keys are also available to simplify and accelerate interactions between the user and the AR scene.

To provide convenient product searching, a product search interface is provided in the AR window, as shown in Figure 4. As a result, users do not need to exit the AR application every time they want to find another product at web page level and then reopen another AR application for comparing products. Several capabilities were also developed to make product searching efficient, such as searching by keywords, sorting by properties, image viewing, listing operations, and displaying prices. With the tool, users can recursively search for and switch product models in an AR display, to compare products, and thus gain enough direct information to make purchasing decisions. Within the system, for tracking purposes, different markers are used which correspond to different types of products. As a result, online shoppers can also combine different types of products together when shopping. For example, a shopper can combine a table with different chairs or sofas to check the appearance of different combinations in their home.

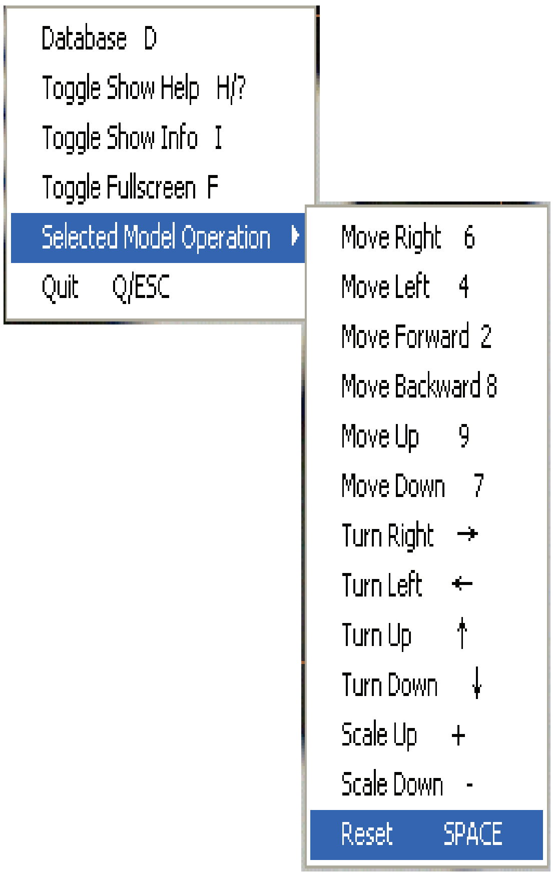


Fig. 3. User interface menu system

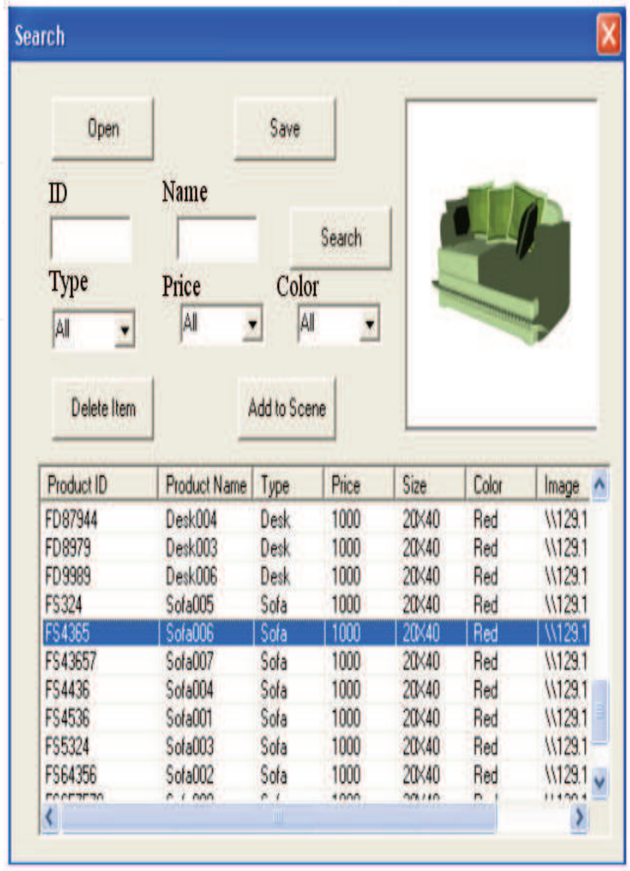


Fig. 4. Product search interface

With models selected from a well-built and normalized database of product loaded to the AR scene, the products can be visualized in actual size within the live background environment which is captured by the local video camera. Users can also pick one of virtual products and manipulate it, for example, move or rotate the model, and view specific information about the selected product, such as name, price, size, and color, to help them make their purchasing decision.
With AR e-commerce, users can have special interactions, which are not available with other applications. Users can walk around their environment, with their laptop, PDA, or cell phone and camera, to see how a product fits in their environment from different viewpoints, as shown in Figure 5. Users can also interact with the AR scene by moving or rotating markers used for tracking.
As mentioned above, the ARToolkit library is used for marker-based tracking in real scenes (Kato and Billinghurst, 1999). Large markers are used for large virtual objects, such as furniture, as shown in Figure 6. Using large markers makes recognition and registration easier and more reliable. With large markers, online consumers can bring virtual furniture or other large virtual products into their homes, and view them from greater distances. Other techniques would cause more instability, since marker tracking is based on computer vision technology. Product models also need to be normalized with respect to marker size so that users see product models in actual size to help them make better buying decisions.

Fig. 5. A virtual model in a real scene

Fig. 6. A Big marker was used

4. Usability Study

A usability study was conducted to compare the developed AR-enhanced e-commerce system with a traditional e-commerce system and a VR-enhanced e-commerce system. To avoid web page design bias, all three web pages were designed using the same design template, which included a word description of the product and a visualization of the product, as shown in Figures 7.-9. The word description parts of the three e-commerce web pages were the same. The only difference among the three types of e-commerce systems was in the visualization component.

For visualization, traditional e-commerce web pages typically use several static 2D pictures of a product, from different perspectives, as shown in Figure 7. With a traditional e-commerce web page, users can visually examine the static 2D product pictures before they buy the product. They can also usually interactively switch between the images. The traditional method is the most commonly used e-commerce approach generally used today.

VR-enhanced e-commerce web pages typically use JAVA applets for visualization. The JAVA applets dynamically download 3D product models in real-time and provide different manipulation capabilities (translate, rotate, zoom) to users, as shown in Figure 8. With VR-enhanced e-commerce web pages, users can easily control and select viewpoints for looking at virtual product models. There might be different types of VR e-commerce web pages. However, this type of design is more representative, since similar types of designs have been used in prior user studies of VR e-commerce (Daugherty 2005) in commercial websites, such as Compaq.com and Dell.com.

Our AR-enhanced e-commerce web page uses ActiveX controls for visualization, as described earlier. System users can visually bring products into their actual physical environments, as shown in Figure 9. With the developed AR-enhanced system, users can hold a laptop, which has a camera, and move around their environment to see how a virtual product model looks, corresponding to the traditional translation, rotation, and zoom interactions in VR e-commerce, and pick operations in traditional e-commerce, and then decide if they want to buy the product. They can also move markers to position the virtual products at different locations to help them make their buying decisions. Figure 10. shows an example of our AR e-commerce system running on a laptop. To control different interaction bias with VR e-commerce and traditional e-commerce, during the user study, participants were not asked to use the developed AR e-commerce menu system.

Fig. 7. Traditional e-commerce with three static 2D images

Fig. 8. VR e-commerce with interactive 3D model

Fig. 9. AR e-commerce interface

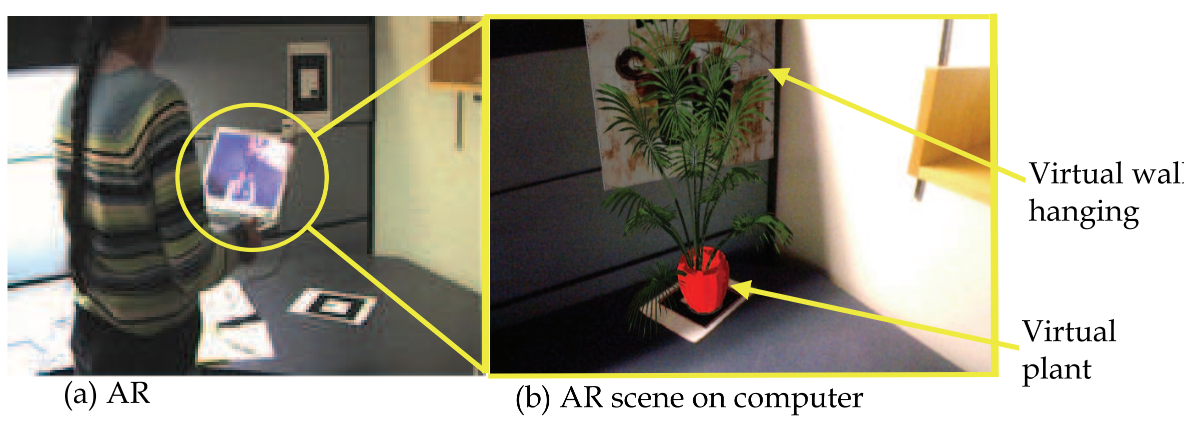


Fig. 10. AR application running on a laptop computer

4.1. Experiment Design

Based on a pilot user study for home furniture products (Lu and Smith, 2006), a formal user study was designed and conducted to test the usability of the developed AR e-commerce system. In the full study, different types of e-commerce web pages were designed for office products (wall hangings and decorative plants) to avoid product-based bias, as shown in Figure 11.

The experiment was designed as within-subjects for types of e-commerce, so that each subject accessed all three e-commerce systems because subjects inevitably differ from one another. In between-subject designs, these differences among subjects are uncontrolled and are treated as error. In within-subject designs, the same subjects are tested in each condition. Therefore, differences among subjects can be measured and separated from error (Howell 2007). Removing variance due to differences between subjects from the error variance greatly increases the power of significance tests. Therefore, within-subjects designs are almost always more powerful than between-subject designs. Since power is such an important consideration in the design of experiments, this study was designed as a within-subjects experiment to compare user's subjective satisfaction level of using the three different types of e-commerce systems. As a result, by design, different participants' rating standards should not affect the comparisons.

Tests were carried out with six volunteer participants in each of the four office environments. In total, twenty-four participants were tested in the experiment. At the beginning of the experiment, participants were trained to use the three types of e-commerce systems. During the experiment, real-time help concerning how to use the systems was also provided. In the test, participants were asked to use the three types of e-commerce systems to buy different office products for the different environments, without considering budget. Users were asked to select wall hangings and decorative plants and then compare the three types of e-commerce systems. During the experiment, the process was recorded and observed. After the experiment, participants were asked to fill out a questionnaire and to give their evaluations of usability. Four main variables (overall evaluation, information provided, ease of use, and confidence level in the final decision) were measured for each type of e-commerce system for each participant.

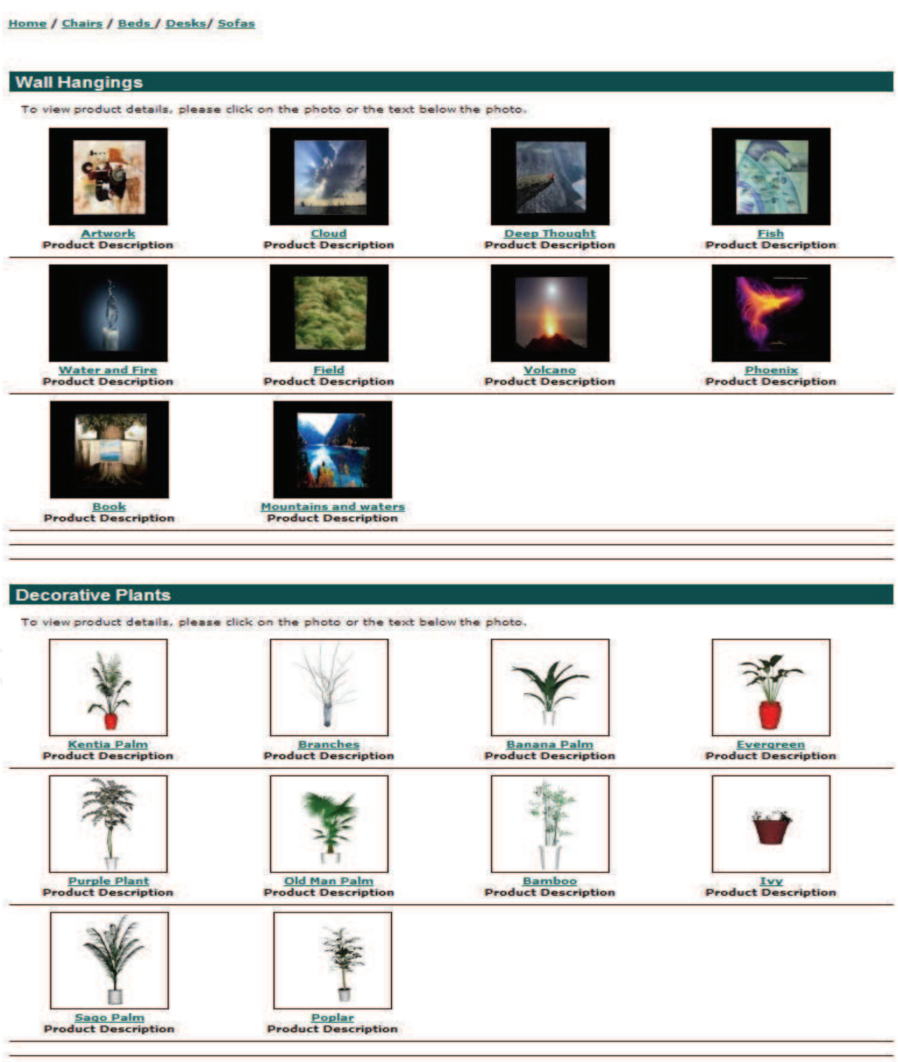


Fig. 11. Office products

In the study, the independent variables were the three different types of e-commerce systems, four different environments (an open space office, a cubicle, a single-user single-room office, and a multi-user single-room shared office). Within each environment, presentation of the e-commerce systems was systematically varied to control the "carryover" effects of a within-subjects design. Since we assigned 6 subjects to each environment, we were able to test all possible presentation orders of the three e-commerce systems (3 choose 1 * 2 choose 1 * 1 choose 1) = 6 different testing orders: (T, VR, AR), (T, AR, VR), (VR, T, AR), (VR, AR, T), (AR, T, VR), and (AR, VR, T). The dependent variables in the research question were four main variables: overall evaluation, information provided, ease of use, and confidence level in the final decision.

To test whether the usability results were affected by experience order, the six user study participants in each of the four environments were randomly assigned to one of the six orders. Evaluations of the four main variables were also compared for the different orders. The formal study addressed the following hypotheses:

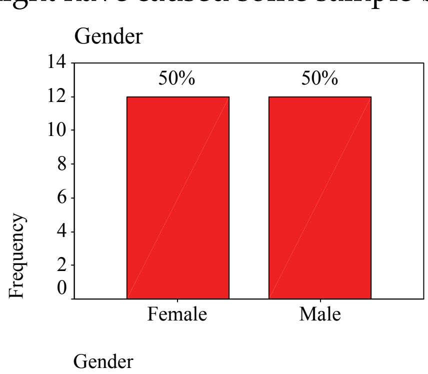
- *Hypothesis 1*: The overall evaluation and satisfaction level of using the AR e-commerce system is higher than using the other two e-commerce systems.
- *Hypothesis 2*: The AR e-commerce system provides more visualization information to online shoppers than the other two e-commerce systems.
- *Hypothesis 3*: The ease of use rating for the AR e-commerce system is lower than the other two e-commerce systems.
- *Hypothesis 4*: Users of the AR e-commerce system have a higher confidence level in their final decision than users of the other two e-commerce systems.
- *Hypothesis 5*: User performance in the different e-commerce systems is not affected by locations.

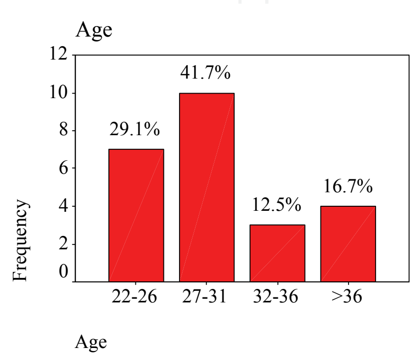
To test the 5 hypotheses, different ratings given by the participants, after using the three types of e-commerce systems, were compared.

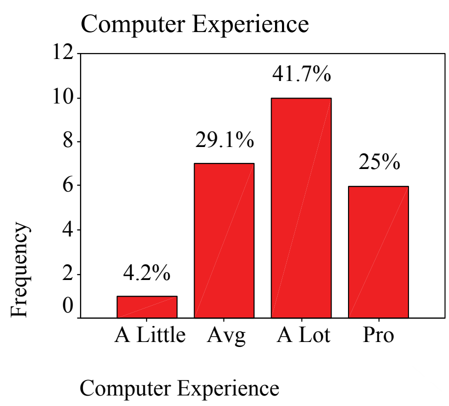
4.2. Experiment Participants

All participants for the study were individuals from Iowa State University who responded to an invitation email. They represented students, staff, and faculty. Figure 12. shows the composition of subjects for the study.

Figure 12. shows that the gender of participants was equally distributed. Since most of the participants were students, the age distribution of participants was skewed toward lower age groups, and computer experience level was skewed toward high levels ("A little" mean little computer experience while "Pro" means professional computer experience), which might have caused some sample bias.







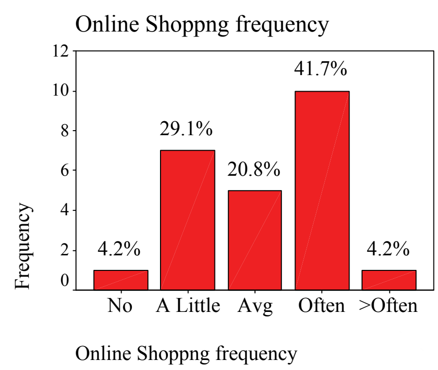


Fig. 12. Participants' self description

4.3 Results

4.3.1 Overall Evaluation

The first research question in the questionnaire was designed to capture overall feelings about the three different types of e-commerce systems, without being affected or guided by later questions. The participants' overall evaluations are listed in Table 1, by locations and by experience orders, which were also separately tested using Factorial ANOVA.

LOCATION	SUBJECTS	PARTICIPANT RATING		
		T	VR	AR
Open space office (1)	1	2	4	5
	2	1	5	5
	3	1	3	4
	4	2	3	5
	5	1	3	4
	6	2	4	5
	Mean/Std. Dev	1.5/0.548	3.667/0.816	4.667/0.516
Cubicle office (2)	7	3	5	4
	8	2	5	4
	9	2	3	4
	10	1	5	5
	11	3	4	5
	12	1	3	5
	Mean/Std. Dev	2/0.894	4.167/0.983	4.5/0.548
Single-user single-room office (3)	13	3	5	5
	14	1	3	5
	15	3	3	5
	16	5	4	4
	17	1	3	5
	18	1	3	5
	Mean/Std. Dev	2.333/1.633	3.5/0.837	4.833/0.408

Multi-user single-room shared office (4)	19	3	4	5
	20	3	4	5
	21	2	3	4
	22	1	2	4
	23	3	4	4
	24	5	5	4
	Mean/Std. Dev	2.833/1.329	3.667/1.033	4.333/0.516
Mean		2.167	3.75	4.583
Std. Dev.		1.204	0.897	0.504

Table 1. Overall evaluation (1=lowest 5=highest)

As shown in Table 1., the mean overall evaluation for traditional e-commerce was 2.167, the mean overall evaluation for VR enhanced e-commerce was 3.75, and the mean overall evaluation for AR enhanced e-commerce was 4.583. As shown in the between-subjects effects and within-subjects effects analysis of Table 2., the p-value for the effect of the type of e-commerce system is very small (<0.05), which indicates that there is a statistically significant difference in mean overall evaluations between the three types of e-commerce systems. In contrast, the p-values for the effect of location is 0.7913, which indicates that there is no statistically significant difference in mean overall evaluations for different locations.

Figures 13., clearly shows that the main effect for different types of e-commerce systems is obvious and that the overall evaluation for the AR e-commerce system is higher than the ratings for the traditional and VR e-commerce systems. The p-value for interaction between types and locations is 0.1407, which indicates that there are no statistically significant interaction effects for types and locations. Thus, interaction effects, and location effects were neglected in the refined analysis model shown in Table 3.

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIG.
Location	3	1.2222	.4074	.3476	.7913
Error	20	23.4444	1.1722		
Type	2	72.3333	36.1667	55.1695**	.000**
Location*Type	6	6.7778	1.1296	1.7232	.1407
Error	40	26.2222	.6556		

**p<0.05

Table 2. Tests of Between-Subjects Effects and Within-Subjects Effects (Dependent Variable: Overall evaluation)

	N	Subset		
Type		1	2	3
Traditional	24	2.1667		
VR	24		3.7500	
AR	24			4.5833
SIG.		1.000	1.000	1.000

Table 3. Homogeneous Subsets Tukey HSD (Dependent Variable: Overall evaluation)

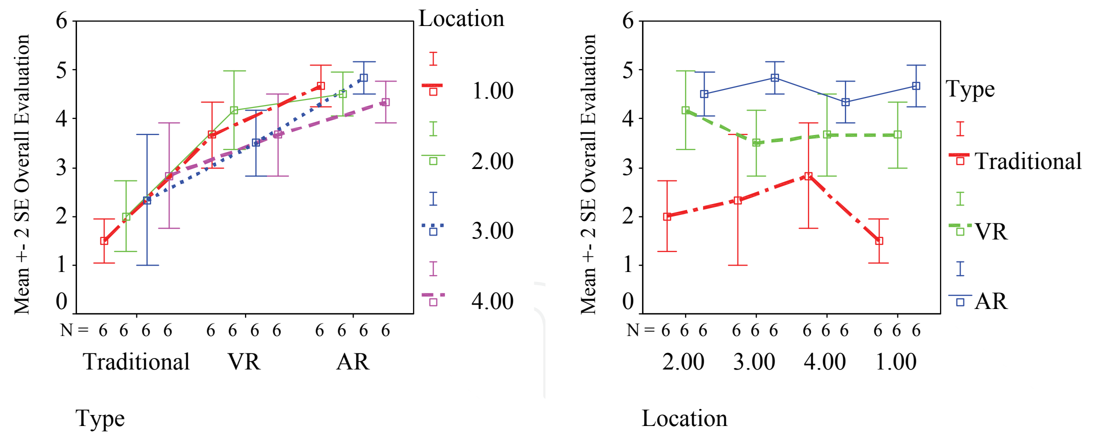


Fig. 13. Interaction between type and location for Overall evaluation

To determine differences in overall evaluations for the three types of e-commerce systems, multiple mean comparisons (Tukey HSD) was used. The analysis results in Table 3. show that each pair of mean overall evaluations for the three types is significantly different.

In comparing the three e-commerce systems, the AR enhanced e-commerce was rated highest by users, which indicates that users preferred the AR enhanced e-commerce system more than the other two for office decoration. Therefore, research hypothesis 1 is accepted. Based on the strength and weakness of AR e-commerce compared to the other two types of e-commerce, customers still preferred AR e-commerce. One of the participants stated, “It is a very high potential method, especially for products like furniture.” From the statistical analysis of survey results, there is also no significant evidence that location has any effect on users’ overall evaluations. Therefore, the AR e-commerce approach appears to be generally useful in various environments.

4.3.2 Visualized Information Provided

In the questionnaire, users were asked to rate how much information they gained from the three different types of e-commerce systems. Participants’ ratings for information provided are listed in Table 4., by locations and by experience orders, which were also tested separately using Factorial ANOVA.

From Table 4., the mean rating for information provided by the traditional e-commerce system was 1.958, the mean information provided by the VR-enhanced e-commerce system was 3.542, and the mean rating for information provided by the AR-enhanced e-commerce system was 4.542. As shown in the between-subjects effects and within-subjects effects analysis of Table 5., the p-value for the effect of type of e-commerce system is very small (<0.05), which indicates that there is a statistically significant difference in mean information provided between the three types of e-commerce systems. However, the p-value for the effect of location is 0.9555, which indicates that there is no statistically significant difference in mean information provided for different locations and different experience orders.

Figure 14. clearly shows that the information users gained from the AR e-commerce system was more than the information they gained from the traditional and VR e-commerce systems. The p-value for the interaction between type and location is 0.9677, which indicates that there was no statistically significant interaction effect between type and location. Thus, the location effect, and interaction effects on information provided were neglected in the refined analysis model shown in Table 6.

To determine the differences between the information users gained for the three types of e-commerce systems, Tukey HSD was used, without considering location or order. With an experiment-wise error rate of 0.05, Table 6. shows that the differences in information provided between the AR e-commerce system and both the traditional e-commerce and VR enhanced e-commerce system are both statistically significant. So the research hypothesis 2 is accepted. Participants also mentioned, in their feedback, that the AR e-commerce system provides the capability to see how products fit in the physical space, so that they can gain more visualization information: "It is very vivid, as if you put a real product into the place where you want. You can efficiently evaluate product information, such as color and size, and determine whether it can match with the scene very well."; "It can provide people an interesting experience and help people gain more information and a much more correct judgment." In addition, statistical analysis of survey results showed that there is no significant evidence that location has an effect on information provided.

LOCATION	SUBJECTS	PARTICIPANT RATING		
		T	VR	AR
Open space office (1)	1	3	3	3
	2	1	3	5
	3	1	3	5
	4	3	4	5
	5	1	4	4.5
	6	3	4	5
	Mean/Std. Dev	2/1.095	3.5/0.548	4.583/0.801
Cubicle office (2)	7	3	4	4.5
	8	2	4	4
	9	2	2	5
	10	1	3	4
	11	3	5	4
	12	1	2	5
	Mean/Std. Dev	2/0.894	3.333/1.211	4.417/0.492
Single-user single-room office (3)	13	3	5	5
	14	1	3	5
	15	1	4	4
	16	4	5	4
	17	1	3	5
	18	1	3	5
	Mean/Std. Dev	1.833/1.329	3.833/0.983	4.667/0.516
Multi-user single-room shared office (4)	19	3	4	5
	20	2	4	5
	21	1	3	4
	22	1	3	4
	23	2	3	4
	24	3	4	5

	Mean/Std. Dev	2/0.894	3.5/0.548	4.5/0.548
Mean		1.958	3.542	4.542
Std. Dev.		1.000	0.833	0.569

Table 4. Information provided (1=lowest 5=highest)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIG.
Location	3	.3472	.1157	.1062	.9555
Error	20	21.8056	1.0903		
Type	2	81.4444	40.7222	69.4787**	.000**
Location*Type	6	.7778	.1296	.2212	.9677
Error	40	23.4444	.5861		

**p<0.05

Table 5. Tests of Between-Subjects Effects and Within-Subjects Effects (Dependent Variable: Information Provided)

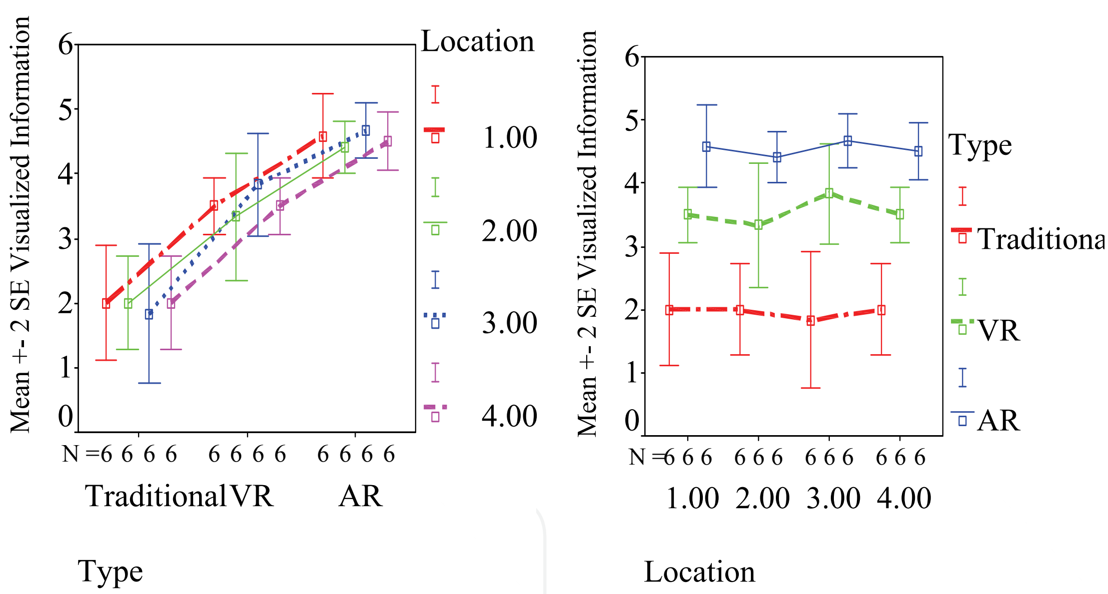


Fig. 14. Interaction between type and location for Information Provided

	N	Subset		
Type		1	2	3
Traditional	24	1.9583		
VR	24		3.5417	
AR	24			4.5417
SIG.		1.000	1.000	1.000

Table 6. Homogeneous Subsets Tukey HSD (Dependent Variable: Information Provided)

4.3.3 Ease of Use

Participants' ratings concerning ease of use for the three different types of e-commerce systems are listed in Table 7., by location and by experience order, which were also tested separately using Factorial ANOVA.

LOCATION	SUBJECTS	PARTICIPANT RATING		
		T	VR	AR
Open space office (1)	1	5	4	2
	2	5	1	5
	3	5	4	3
	4	2	3	5
	5	5	4.5	4.5
	6	2	5	4
	Mean/Std. Dev	4/1.549	3.583/1.429	3.917/1.201
Cubicle office (2)	7	5	5	3
	8	4	4	4
	9	5	3	2
	10	5	5	4
	11	4	5	3
	12	5	4	3
	Mean/Std. Dev	4.667/0.516	4.333/0.816	3.167/0.753
Single-user single-room office (3)	13	5	4	4
	14	5	5	5
	15	5	4	5
	16	5	4	3
	17	5	4	3
	18	5	4	2
	Mean/Std. Dev	5/0	4.167/0.408	3.667/1.211
Multi-user single-room shared office (4)	19	5	5	3
	20	5	3	5
	21	4	4	3
	22	5	3	2
	23	4	4	3
	24	5	5	3
	Mean/Std. Dev	4.667/0.516	4/0.894	3.167/0.983
Mean		4.583	4.021	3.479
Std. Dev.		0.881	0.938	1.037

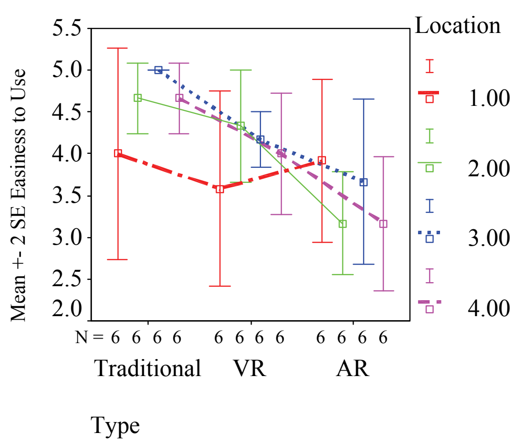
Table 7. Ease of use (1=lowest 5=highest)

The mean ease of use for the traditional e-commerce system was 4.583, the mean ease of use for the VR enhanced e-commerce system was 4.021, and the mean ease of use for the AR enhanced e-commerce system was 3.479. As shown in the between-subjects effects and within-subjects effects analysis of Table 8., the p-value for the effect of type of e-commerce system is 0.0027 (<0.05), which indicates that there is a statistically significant difference in mean ease of use between the three types of e-commerce systems. In contrast, the p-value for the effect of location is 0.4033, which indicates that there is no statistically significant difference in mean ease of use for different locations.
Figure 15. shows the main effect of different types of e-commerce systems. Ease of use for the AR e-commerce system is much lower than ease of use for the traditional and for the VR e-commerce systems. The p-value for the interaction effect between type and location is 0.5186, which indicates that there are also no statistically significant interaction effects for type and location or type. Thus, the interaction effects, for ease of use were neglected in the refined analysis model shown in Table 9.

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIG.
Location	3	1.9444	.6481	1.0234	.4033
Error	20	12.6777	.6333		
Type	2	14.6319	7.3160	6.8721**	.0027**
Location*Type	6	5.6181	.9363	.8795	.5186
Error	40	42.5833	1.0646		

**p<0.05

Table 8. Tests of Between-Subjects Effects and Within-Subjects Effects (Dependent Variable: Easiness to Use)



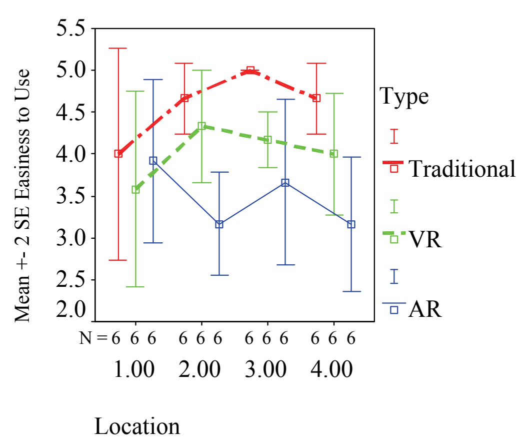


Fig. 15. Interaction between type and location for Easiness to use

	N	Subset	
Type		1	2
AR	24	3.4792	
VR	24	4.0208	4.0208
Traditional	24		4.5833
SIG.		.128	.110

Table 9. Homogeneous Subsets Tukey HSD

To determine the differences between ease of use for the three types of e-commerce systems, Tukey HSD was used, without considering location or order. With an experiment-wise error rate of 0.05, Table 9. shows that the difference in ease of use between the traditional e-commerce system and the VR enhanced e-commerce system is not statistically significant. The difference between the VR enhanced e-commerce system and the AR enhance e-commerce system is also not statistically significant. However, ease of use for the traditional e-commerce system is significantly better than ease of use for the AR enhanced e-commerce system.

So the research hypothesis that ease of use for the AR e-commerce system is lower than for the traditional e-commerce systems is accepted. Participants mentioned in their feedback that the AR e-commerce system needs more high-end hardware equipment, and that it is inconvenient to use: "It is not very convenient to hold the laptop with your hands all the time." There are two explanations for the finding. The first is that AR e-commerce uses more devices and needs more computer skills. The second is that users were still not familiar with AR and AR system interactions. Meanwhile, there is also no significant evidence that location has significant effects on ease of use.

4.3.4 User Confidence Level for Decision

The final main dependent variable measured in the questionnaire was the user's confidence level in their decision (buy or not buy). Participants' ratings are listed in Table 10., by location and by experience order, which were also tested using Factorial ANOVA.

The mean user confidence level for the Traditional e-commerce system was 2.25, the mean user confidence level for the VR enhanced e-commerce system was 3.542, and the mean user confidence for the AR enhanced e-commerce system was 4.646. As shown in the between-subjects effects and within-subjects effects analysis of Table 11., the p-value for the effect of type of e-commerce system is very small (<0.05), which indicates that there is a statistically significant difference in user confidence level between the three types of e-commerce systems. However, the p-value of the effect of location is 0.1184, which indicates that there is no statistically significant difference in user confidence level for different locations.

Figures 16. clearly shows the main effect for different types. User confidence level for the AR e-commerce is much higher than user confidence level for either the traditional or the VR e-commerce systems. The p-value for the interaction effect of type and location is 0.3923, which indicates that there is no statistically significant interaction effect for type and location, Thus, location effect, and interaction effects on user confidence level were neglected in the refined analysis model as shown in Table 12.

To determine the differences in user confidence level for the three types of e-commerce systems, Tukey HSD was used, without considering location or order. With an experiment-wise error rate of 0.05, Table 12. shows that the difference in user confidence level between the AR e-commerce system and both the traditional e-commerce system and the VR enhanced e-commerce system was statistically significant.

The results show that users had a higher confidence level in their shopping decisions when using the AR enhanced e-commerce system, rather than the other two e-commerce systems, for purchasing office decoration products. Therefore, research hypothesis 4 is accepted. Participant comments included: "AR e-commerce makes shopping more visually intuitive."; "The user naturally sees what will happen before actually buying."; "It gives you a real-time experience in your own environment so that you can instantly tell whether or not the product is a good fit." Meanwhile there was also no significant evidence that location had an effect on user confidence level.

LOCATION	SUBJECTS	PARTICIPANT RATING		
		T	VR	AR
Open space office (1)	1	2	2	4
	2	1	3	5
	3	1	3	4
	4	2	4	5
	5	1	4	4.5
	6	2	3	5
	Mean/Std. Dev	1.5/0.548	3.167/0.752	4.583/0.491
Cubical office (2)	7	2	5	4
	8	2	4	5
	9	3	4	5
	10	2	4	3
	11	3	4	5
	12	1	2	5
	Mean/Std. Dev	2.167/0.752	3.833/0.983	4.5/0.837
Single-user single-room office (3)	13	3	4	5
	14	3	5	5
	15	4	3	5
	16	4	4	3
	17	1	3	5
	18	2	3	5
	Mean/Std. Dev	2.833/1.169	3.667/0.816	4.667/0.816
Multi-user single-room shared office (4)	19	3	4	5
	20	2	3	5
	21	3	4	5
	22	2	4	5
	23	2	3	4
	24	3	3	5
	Mean/Std. Dev	2.5/0.548	3.5/0.548	4.833/0.408
Mean		2.25	3.542	4.646
Std. Dev.		0.897	0.779	0.634

Table 10. User **c**onfidence level for decision (1=lowest 5=highest)

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIG.
Location	3	4.2049	1.4016	2.2107	.1184
Error	20	12.6806	.6340		
Type	2	69.0208	34.5104	64.6229**	.0000**
Location*Type	6	3.4514	.5752	1.0772	.3923
Error	40	21.3611	.5340		

**p<0.05

Table 11. Tests of Between-Subjects Effects and Within-Subjects Effects (Dependent Variable: User Confidence Level for Decision)

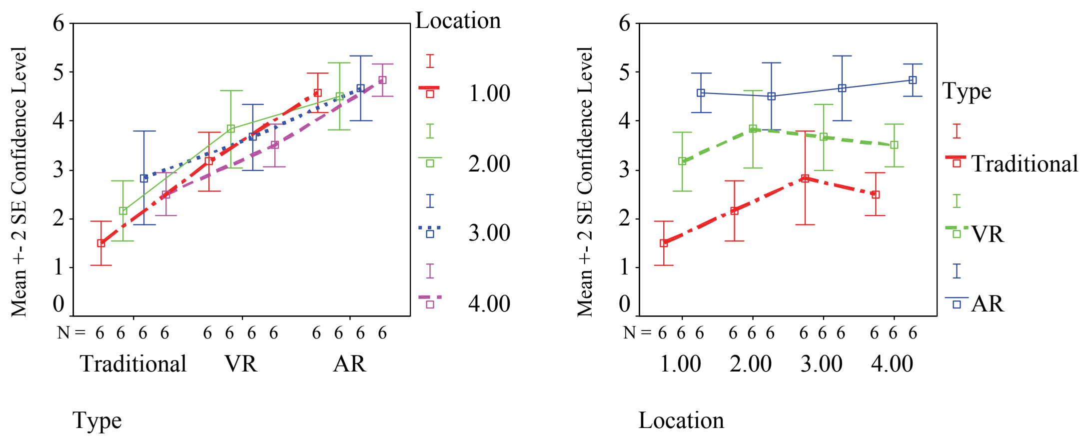


Fig. 16. Interaction between type and location for Confidence Level for Decision

	N	Subset		
Type		1	2	3
Traditional	24	2.2500		
VR	24		3.5417	
AR	24			4.6458
SIG.		1.000	1.000	1.000

Table 12. Homogeneous Subsets Tukey HSD (Dependent Variable: User Confidence Level in Decision)

4.4 Observations and Users' Comments

4.4.1 "As Is" View

95.8% of participants mentioned, in their feedback, that the AR e-commerce system provides the capability to see how products fit in the physical space. Users' comments included: "It is visually intuitive."; "The user naturally sees what will happen before actually buying."; "It gives you a real-time experience in your own environment so that you can instantly tell whether or not the product is a good fit."; "It presents products in a real scale relative to the environment, and is able to show views from several perspectives."; "AR makes shopping more confident."; "It is cool and helpful for making the decision."; "It is very vivid, as if you put a real product into the place where you want. You can efficiently evaluate product information, such as color and size, and determine whether it can match with the scene very well."; "It can provide people an interesting experience and help people gain more information and a much more correct judgment."

4.4.2 Ease of Use
87.5% of participants mentioned in their feedback that the AR e-commerce system needs more high-end hardware equipment, and that it is inconvenient to use. Users' comments included: "You have to have a laptop or mobile device."; "It is not very convenient to hold the laptop with your hands all the time."; "It is constrained to a marker."; "It is limited to certain viewing areas."; "If the designer could use a small device (like a cell phone) to replace the laptop, it would be more convenient for customers."; "It is slower for the user and more complicated."; "If it was more user friendly and more easy to use, it would be widely used."; "Not as convenient as VR and traditional e-commerce."
However, 12.5% of participants believed that the AR e-commerce system was convenient to use. Users' comments included: "It is very easy."; "There is not much I have to learn to dive right in."; "It is friendly and looks real."; "It is easy to manipulate. It is a more natural interactive method than mouse interaction."; "It is more convenient, and otherwise, it is difficult to shop at onsite stores that are far away."

4.4.3 Unstable
29.2% of participants mentioned in their feedback that the AR e-commerce system is unstable: "The images on the screen are not stable, and sometimes disappear due to problems with light intensity."; "If people could easily change the position of the target, without considering light problems, it would be better."; "The smoothness of motion tracking needs to be improved."; "There are limited spots where you can see the product."; "Sometimes I cannot see the virtual image."

4.4.4 Real Modeling and Rendering
25% of participants said that the virtual objects in the AR e-commerce display were not very real: "If it looked more realistic, it would be better."; "If the models looked the same as the real objects, it would be better."; "The model should be designed more accurately."; "It needs some easy way to directly transfer real things into 3D virtual models."; "It needs accurate illumination."; "It would be great if I could feel the texture of a product".

4.4.5 Internet Speed
25% of participants felt that the Internet wireless connection speed used was not fast enough for AR e-commerce. They considered the process of downloading models to be slow. However, they believed this problem would be solved with further development of technology. One user said: "While I thought that the quality of the graphics of the product would be an issue, I found that the AR system provided me with an excellent sensation of the product. The lack of a very high graphical representation of the product did not bother me at all."

5. Discussion and Conclusions

Traditional e-commerce systems have reached a limitation that needs to be overcome, because they do not provide enough direct information for online shoppers, especially when they are shopping for products like furniture, clothing, shoes, jewelry, and other decorative products. In this study, we developed an AR e-commerce system and studied the effectiveness of AR for enhancing e-commerce.

A formal usability study was designed and conducted. Usability experiment results verified that the developed AR e-commerce system could be used to provide more direct product information to online shoppers and thereby help them make better purchasing decisions. Additionally, in the study, users preferred the AR e-commerce system more than traditional e-commerce and VR e-commerce systems.

Although the AR e-commerce system provides more information and interaction capability than the other e-commerce systems, it is also evident that some limitations still exist in the proposed approach. According to the study participants, the major limitation of using the AR e-commerce system is that it is currently not as easy to use as the traditional or VR e-commerce systems. The AR e-commerce system's interaction method still needs to be improved, to make it more convenient for users. For example, the system could offer online shoppers differet modes for using the system. Such as uploading static pictures with markers, or uploading pre-made videos so that users do not need to carry a laptop computer around for viewing each product. The application could also be implemented on PDAs and cell phones, which are available to most consumers and which are also light and easy to carry.

The rendering methods used also need to be improved to help integrate virtual models into real scenes more seamlessly. For example, more texture mapping could be used to improve virtual product realism. Real time occlusion could also be implemented to help consumers' depth perception and visualization of virtual products placed in their environments. The computer vision algorithm used in the AR system needs to be improved, to make the marker tracking more stable, even in a poor lighting condition. New and better algorithms should also be studied and developed for partial marker tracking so that users do not need to worry about the virtual product disappearing because the marker is partially occluded. In addition, the system should be updated to use the latest high-speed wireless Internet technology, when available, since current wireless Internet technology is currently still not fast enough to transfer high-resolution product models in real-time.

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