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Improving E-Commerce Application through Sense of Agency of a Calibrated Interactive VR Application

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ABSTRACT

Virtual reality (VR) technologies create and control different virtual worlds instead of the actual environment, and this contributes to the feeling of control known as the sense of agency (SoA). The SoA exists from the contrast between the expected sensory consequence of one's action from the efference copy and the real sensory effects. However, the size representation of objects differs between the physical and virtual worlds due to certain technical limitations, such as the VR application's virtual hand not reflecting the user's actual hand size.

These limitations will incur low quality of perception and SoA for digital application. This paper proposed a proof-of-concept of an interactive e-commerce application that incorporates VR capability and size calibration mechanism. The mechanism used a calibration method based on the reciprocal scale factor from the virtual object to its real counterpart. A study of SoA focusing on user perception and interaction was conducted. The proposed method was tested on 22 participants who were also online shopping users. Nearly half of the participants (45%) bought online products frequently, with at least one transaction per day. The outcome indicated that the proposed method improved 47 percent of user perception and interaction as compared to the conventional e-commerce application with its static texts and images. The proposed method is rudimentary yet effective and can be easily implemented in any digital field.

Keywords: Virtual environment, sense of agency, virtual hand, online shopping.

INTRODUCTION

This paper introduces a calibration mechanism that improves user perception and interaction in the digital domain. The mechanism is a calibration method based on the reciprocal scale factor from the virtual object to its real counterpart. Higher accuracy in virtual reality (VR) allows users to interact in a more intuitive and non-intrusive manner. This paper proposes a proof-of-concept interactive that incorporates the calibration mechanism, and a study has been conducted on users with this prototype. The study is based on SoA scores that focus on user perception and interaction with the prototype. The outcome indicates that the proposed method improves 47 percent in terms of user perception and interaction as compared to the conventional e-commerce application. It is important to note that the proposed method is not necessarily limited to e-commerce applications but also other domains such as medical, military, and education. The proposed method is simple yet effective and can be easily implemented in any digital field. This simple and effective calibration method could possibly open a new and effective application outside of the e-commerce domain in the future.

The sense of agency (SoA) or feeling of control is the subjective awareness of initiating, executing, and controlling one's behaviours in the real world (Jeannerod, 2003). Studies have shown that the firmer the SoA, the greater the individual's belief in interacting with the digital environment (Sanchez-Vives & Slater, 2005). SoA is also an essential element in technology, user interface interaction, and perception (Martinez Cornelio et al., 2017; 2018; 2020). SoA has also been used to test virtual hand control and task efficiency (Argelaguet et al., 2016).

SoA is limited in e-commerce since users only obtain information regarding the goods' scale and dimensions through text descriptions or photos (Patel, 2015). To improve the SoA, one can introduce VR (Young et al., 2015), which will allow users to interact and inspect the tangible goods inside the virtual environment (VE). To achieve this, the correct dimension should be included in VR, where a user should be able to hold and inspect the goods (e.g., a mobile phone) virtually. However, due to certain technical restrictions in VR, the real object representation (e.g., hand) is made constant, making the object's size estimation a challenge (Jung et al., 2018). VR applications, especially with hand representation (e.g., Ultraleap), use the same size of hand − average hand size of an adult − in VR configured by the software, regardless of the actual size of the user's hand. Therefore, the size of the virtual hand will be meaningless as a comparison mechanism in VR since it is not relatively the same size as the user's real hand. The avatar hand is rather bigger or smaller as compared to the actual hand. This problem will eventually lead to false user perception and interaction. VR applications with this deficiency will exacerbate, especially those requiring exact imitation of real-life objects, in fields such as surgical (Wang et al., 2018), military (Rathnayake, 2018), e-commerce (Speicher et al., 2018), education (Romli et al., 2003), and architecture (Abu Bakar et al., 2003).

To address this problem, this study proposes an interactive VR application for e-commerce incorporated with a calibration mechanism to represent a real object in VR with higher accuracy. Through the calibration mechanism, users can interact with a virtual environment (VE) in a non-intrusive and intuitive manner while benefiting from the increased accuracy (Wilson et al., 2016). The calibration mechanisms in virtual hands are respectively inadequate. Some works apply calibration mechanisms using an external physical input device, such as a glove (Griffin et al., 2000) for VR applications. In contrast, this study's calibration method is done based on the reciprocal scale factor from the virtual object to its real-life counterpart by using a camera sensor. First, the method measures the width of the real hand. Second, it generates the ratio of the measured width to the constant width of the virtual hand. Finally, based on the ratio, the method computes the scale factor and applies it to each virtual object in VR. By doing this, every single object's scale in the VR world is proportionate to the real hand.

The current research developed an e-commerce VR application prototype equipped with the calibration mechanism. Users use the Leap Motion sensor by Ultraleap for calibration purposes and to interact with the VR model. To evaluate the impact of the proposed solution on user interaction and perception, two online shopping application prototypes were built. First, an application with conventional static images, and second, an application that provides both static images and calibrated virtual geometries. The SoA scores were evaluated and the result is reported in this paper. This study also analysed the correlation between the SoA scores and their frequencies.

The motivation for e-commerce is from the International Data Corporation (IDC), which forecasted a skyrocket in digital transformation in every segment starting from 2020 to 2023, including VR devices and applications (Shawn, 2020). According to the IDC, there is good potential for online shopping worldwide, and it is happening even faster due to the COVID-19 pandemic. More people are ordering items from home at any time, every day. However, online shopping platforms lack product visualisation (Speicher et al., 2018; Nasibov et al., 2019). Taking advantage of the advanced technology solutions (e.g., interactions in VE) will enhance the customers' experience and impact their decision-making to purchase a product online (Duarte et al., 2018). On the other hand, the proliferation of studies in VR technologies, devices, and applications, especially from Tech Giants such as Facebook and Google, has shown that studies regarding VR in e-commerce are significant (Thompson, 2020). This work will significantly contribute to the online economy sector.

RELATED WORKS

This paper proposes an interactive VR application for e-commerce incorporated with a calibration mechanism to represent a real object in a VE with higher accuracy. This section will review the relevant literature in the area, identify the limitations and strengths, and determine the key to the proposed method.

Real Object Representation and User Perception in the Virtual Environment

Most people cannot perceive the objects portrayed on display to be the same size as real-world objects. Therefore, it is crucial to improve the perception of the real-world object's representation and its interaction in the VR world. This representation of body size (e.g., hand), particularly in VR, relates to egocentric and allocentric representation (Kilteni & Maselli, 2015). Prior research demonstrated that the capabilities of a person's body movements influence the perception of size and distance. The real body acts as a perceptual ruler to measure the perceived sizes and distances (Linkenauger et al., 2015). For instance, Linkenauger et al. (2015) claimed that the perceptual system treats information about the arm's reach as a depth cue. The visual perception of body parts affects the decisions regarding a person's spatial location. The virtual arm needs visual motor input that extends and reaches to adjust the arm's length as it affects the perceived distance. This influence affects the design and application of self-avatar in the VE. Hoyet and Argelaguet (2016) claimed that size was interpreted more accurately in the VE when more common size cues were available. One type of familiar size cue that can reasonably support size estimation is the user's body (Jung et al., 2018). Jung et al. (2018) found the effects of a personalised hand on spatial presence in a VE. The perceptual matching task with the personalised hand had considerably better precision in object size estimation. By adjusting the virtual avatar's hand, the scale of one's body representations can be altered as well, and the egocentric distance estimation becomes more accurate when personalised scale adjustments of avatars exist. For instance, Aslandere et al. (2015) applied the virtual hand metaphor to interact with virtual objects in a flight simulator – the buttons in an airplane. The virtual hand was presented as a hand avatar scaled according to the real hand. In another work, Ogawa et al. (2019) demonstrated the perceived object sizes between a realistic hand and a virtual hand. The study showed that the more similar the avatar was to the user's real-life measurements, the stronger the sense of embodiment and size comparison was in the digital world. In this paper, the human hand was chosen as a cue to improve the perception in e-commerce since it is a common interaction cue in most interactive VR applications. The hand allows direct control in the VE, which can establish a practical physical interaction experience.

The main challenge with virtual objects is to match their size with real-life objects (Jung, 2018) since some sensors (e.g., Leap Motion) provide the constant size of a virtual hand no matter what the input size is. Nevertheless, the issue with size perception in VE has received little attention from the Human-Computer Interaction (HCI) community. This issue remains a challenge. Prior research mainly focuses on object manipulation, rather than the accuracy of object size perception (Bergström et al., 2019; Park et al., 2021; Dewez et al., 2021). Inaccurate representations of the environment will tamper with the human perception of the VE (Ebrahimi et al., 2018). This will lead to false perceptions since users can only interpret the size of an object based on how they interact with the said object (Witt, 2011). The size and depth perceptions in VR are important since they are correlated and contribute to the object size estimation (Day et al., 2019). To solve this issue, one can use physical props such as in the work by Sait et al. (2018), whereby the researchers used passive props in scenarios analogous to household settings. A user seated at a desk or standing at a table interacted with the physical prop while receiving display feedback. In other works, Kim and Interrante (2017) altered the size and distance of virtual objects. However, the physical prop proposed was less suitable in an e-commerce application. Besides, a mechanism for accuracy assurance such as a calibration method was not reported in the work. The current work proposes VR interaction in an e-commerce application and introduces a naive but effective calibration method to improve size estimations in the digital world.

Sense of Agency

In VR, the user feels immersed in the simulation or the VE. There are four essential VR elements: (1) the virtual environment, (2) virtual presence, (3) sensory feedback as a response to the user's actions, and (4) interactivity. The application of VR can be used to reframe the controlled experience. VR has made it possible for researchers to study the level of existence of the sense of embodiment (SoE). SoE in a body is the sense that emerges as if they were the properties of one's own biological body (Kilteni & Groten, 2012). The three components that contribute to SoE are: (1) body ownership, (2) self-location, and (3) the sense of agency (Kilteni & Groten, 2012). Ownership refers to the feeling that the virtual body is one's own body. Self-location is the feeling that one's body and the virtual body are both in the same place. The sense of agency (SoA) is the feeling of control one has over the virtual parts of the body (Canales et al., 2019).

The effect of experience-driven designs is determined by understanding the control and interaction. When a user's action is precisely mimicked as a virtual representation in real time, the SoA will occur. If the SoA cannot be perceived, the experience becomes more offensive. To produce the SoA in VR, the combination of the principle of body orientation in a VE and its effects are significant. The constructive interference of the SoA in the manipulated VE is substantially higher than in the non-manipulated virtual environment, using the theory that focuses on controlling virtual reality. This SoA can be introduced in e-commerce applications by using the representation (i.e., virtual effector) of a real hand in VR. Ma and Hommel (2015) found the similarity between people's actual hands and the virtual effector, where the effector acts as a tool to control sensorimotor knowledge (Jeunet et al., 2018). In this paper, the method for an interactive e-commerce application is described, and the results of the SoA for both interactive and non-interactive (i.e., conventional) e-commerce applications are presented and discussed.

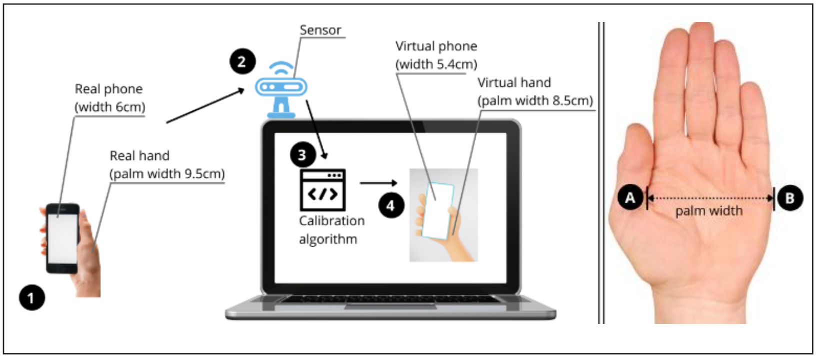
THE CALIBRATED VIRTUAL ENVIRONMENT

Calibration Process

This section explains the proposed calibration method. Given that the virtual hand palm width is constant (8.5 cm), first, the width of the real hand palm was acquired (as shown on the right side of Figure 1) through a leap motion sensor as in steps ① and ② in Figure 1 (left).

Figure 1

The Overview of the Calibration Process – Overview Flow of the Process (Left), the Palm Width Measurement from Point A to B (Right)



The method then used those two values and computed the scale factor (as in step ③). For instance, the width ratio of real to virtual hand is 9.5 cm to 8.5 cm. The scale factor is calculated as in Equation 1:

$$S = \frac{W_v}{W_r} \tag{1}$$

Where:

S = scale factor.
W_v = constant palm width of the virtual hand (8.5 cm).
W_r = palm width of the real hand (9.5 cm).

From Equation 1, the scale factor is equivalent to 0.89. In other words, 1 cm in the real world is equivalent to 0.89 cm in the virtual world.

Finally, the *S* value was used to scale the virtual mobile phone in step ④ of Figure 1 (left) by using the transformation function as in Equation 2:

$$P' = SP \tag{2}$$

Where:

P' = new transformed point (x', y', z')
S = the scale factor ,(Sx, Sy, Sz),
P = the old point (x, y, z).

The scale factor is uniform in all axes, i.e., . Equation $Sx = Sy = Sz.$ (2) can also be written in a matrix form as in Equation 3:

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{pmatrix} Sx & 0 & 0 \\ 0 & Sy & 0 \\ 0 & 0 & Sz \end{pmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{3}$$

It is also important to note that this method can be used for any shape of geometry in the virtual world.

EXPERIMENTAL SETUP

This section describes the experimental prototype, tasks, and procedures.

Prototype

A virtual shopping environment (as in Figure 2) was built by using Unity 2019 to study user interaction and perception of the proposed method. The calibration programme was written in C# language. Figure 3 shows the chronological instructions to use the written programme in which the user will first choose the product from the list, read the details of the product, and run through a calibration procedure before they can inspect the product virtually.

Figure 2

The Virtual Shopping Environment where a Hand is Used to Inspect a Mobile Phone

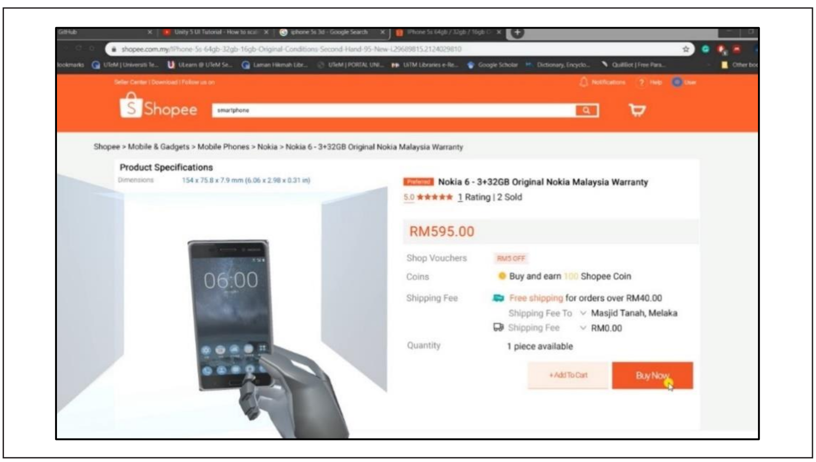
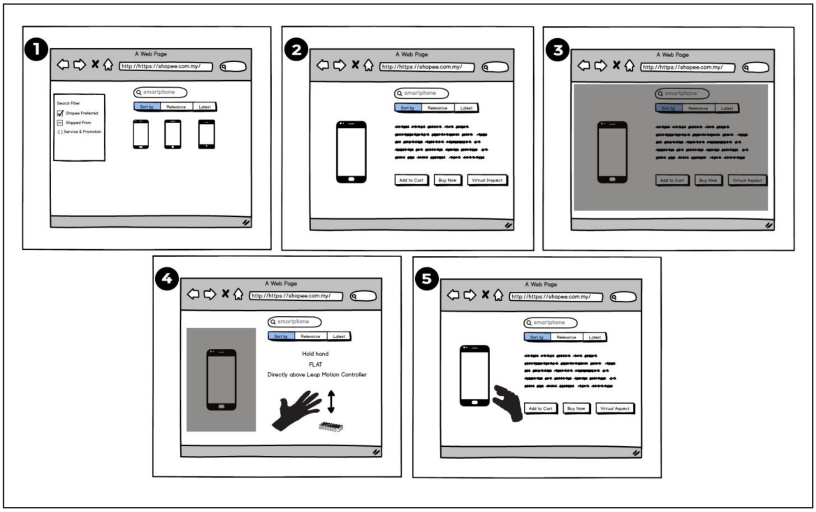


Figure 3

The Instructions for the Application Programme: ① the User Chooses the Product, ② the User Reads about the Product, ③ the User Presses the Button to Inspect the Product Virtually, ④ the User Carries out a Calibration Procedure, and ⑤ the User is Able to Inspect the Product Virtually



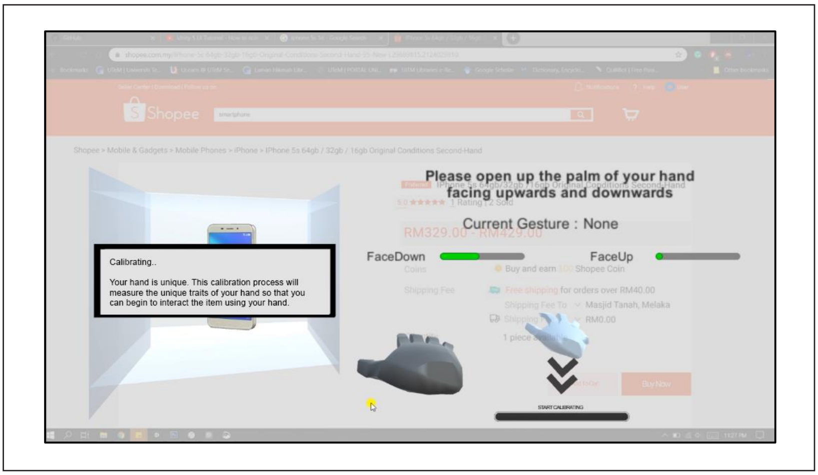
The user goes through a quick one-time calibration procedure. Figure 4 shows a calibration window prompt for the user. The user needs to place their palm in face-up and face-down motions within the sensor's effective range $\approx$ 25 to 600 mm (1 inch to 2 feet) above the device. The calibration's goal is to acquire the palm width of the real hand and compute the scale factor value as explained in the calibration method section. An off-the-shelf Leap Motion sensor (SDK v3.2) was utilised to obtain the palm width of the user and to provide physical interaction capabilities such as grasping. The Leap Motion device provides data with seamless finger tracking features and absence of having to wear gloves. It is a lightweight, affordable, and reliable commercial stereo infrared camera that specialises in tracking the user's hand with a high degree of accuracy (Clark & Moodley, 2016).

The calibration programme is built by using the OMEN15 HP Gaming workstation with specifications: Windows 10 operating system, Intel Core i7 processor, and 12GB RAM. The entire virtual geometry and

3D models were made using Cinema4D. Interacting behaviour and rigid body dynamics were attached to the geometry, and the interacting logic was inspected of its functionality. It is important to note that both the physics engine time step and rendering frame rate should be in sync to avoid any problems in the output.

Figure 4

The Calibration Process Starts with Measuring the Palm Width



Apparatus and Participants

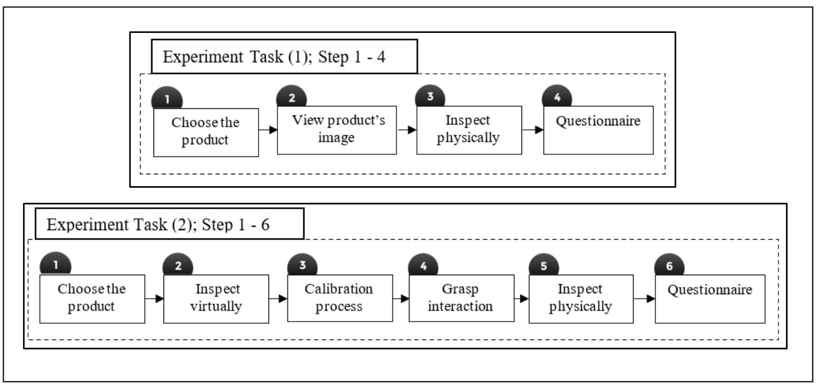
The experimental apparatus included a laptop system and a Leap Motion sensor. The laptop ran on the Windows 10 operating system with 12GB RAM and 1TB storage space. 22 respondents (10 males and 12 females of ranging from 18 to 25 years old) participated in the experiment. All respondents were online shoppers, and none of them had any experience using the Leap Motion sensor. To evaluate the impact of the proposed solution on user interaction and perception, the questionnaire focused on the SoA since it has been proven to improve interaction efficiency of technology and user interface on interaction (Martinez Cornelio et al., 2017; 2018; 2020). The higher the SoA, the better the system will perform. The study adopted the questionnaire form (Ogawa, 2018), with the aim to examine the performance of e-commerce with and without the virtual inspection capability based on the SoA scores.

Procedures

Figure 5 shows the overall procedures for the study. First, the respondents were given a briefing regarding the flow of the experiment and later, would fill in a consent form. The respondents could withdraw at any point of the experiment. Repeated measures experiment was employed for this work whereby data will be collected from the same group of respondents for different experiments. There were two different experiments in this work. Figure 5 shows the diagram of the experimental procedures. In the first experiment, the respondents were tasked to buy a mobile phone through an online shopping application without a virtual inspection function (only texts and photos). There were four steps in the experiment: 1) respondents chose a product via an application that mimicked real online shopping; 2) they inspected the image of the selected product on a page; 3) the selected physical mobile phone would be handed over as a result of the purchase; and 4) the respondents answered a questionnaire.

Figure 5

The Complete Task of the Two Different Experiments



The respondents were given a five-minute break before continuing to the second experiment. In the second experiment, the respondents were tasked to purchase a mobile phone using an online shopping application incorporated with a virtual inspection function. There were six steps in the experiment: 1) respondents chose a product via an application that mimicked real online shopping; 2) they carried out a calibration procedure whereby the calibration mechanism would scale the 3D mobile phone model according to the computed scale factor; 3) the respondents would grasp the virtual mobile phone after the calibration using mid-air interaction; 4) the respondents were later given time to inspect the 3D phone virtually; 5) the selected physical mobile phone would then be handed over to them as a result of the purchase; and 6) the respondents answered a questionnaire. Figure 6 shows the experimental setup of this study.

Figure 6

An Experiment Carried out in this Study

ANALYSIS AND RESULTS

Feedback was collected from 22 respondents of online shopping users. Table 1 below shows questions from the questionnaire to measure the SoA from respondents' feedback. The questionnaire contained seven items and three representations of SoA: control, movement, and representation. The questionnaire was created based on a five-point Likert scoring system (1 – Strongly disagree, 2 – Disagree, 3 – Neither agree nor disagree, 4 – Agree, 5 – Strongly agree). The questionnaire's results, in summary, showed that most respondents preferred having virtual hand representation in online shopping applications.

Table 1

Questionnaire Sample

Conditions	Questions	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
Static Image	1) I felt the images displayed could easily portray the real size and feel of the products.	4	10	8	0	0
	2) I felt like I was able to interact with the product realistically.	6	10	6	0	0
	3) I felt that the images displayed are portrayed in a realistic manner as if the products are right in front of me.	6	8	7	0	0
Virtual Hand Representation	4) I felt as if the virtual representation of the hand moved just like I wanted it to as if it was my own hand.	0	0	2	10	10
	5) I expected the virtual representation of the hand to react in the same way as my own hand.	0	0	3	6	13
	6) I felt like I was able to interact with the product realistically.	0	0	2	8	13
	7) I felt like I controlled the virtual representation of the hand as if it was part of my own body.	0	0	0	13	9

In the analysis, the Shapiro-Wilk's normality test was employed and it was found that the sample was drawn from a normally distributed population. Data were collected using analysis of variance (ANOVA) repeated measures designs in which the data collections were made of the same entities in different experiments. This study also analysed the correlation between respondents and SoA scores and reported the results.

Figure 7 shows the result of the mean SoA scores for applications with and without virtual inspection function. Three elements were tested in this work, namely control, movement, and representation. Control was the variable representing the feeling of control. Meanwhile, representation and movement were the variables representing the visual appearance and feel of the digital mobile phone (either static images or interactive virtual model) as compared to its physical form, which the user acquired after each online shopping session. The figure indicated that the SoA scores of interactive calibrated virtual inspection functions were higher than those that only provided static images. The interactive virtual inspection function brought a significant effect to the SoA scores, $F(2,19) = 36.85$, $p < 0.001$. In Table 2, overall, the proposed method was 47 percent higher than the conventional method (static image). These higher SoA scores showed that the proposed method provided a greater feeling of control, interaction, and perception in the online platform, particularly e-commerce.

Figure 7

Graph of Mean Sense of Agency (SoA) Scores with SoA Elements for Applications with and Without Virtual Inspection Function

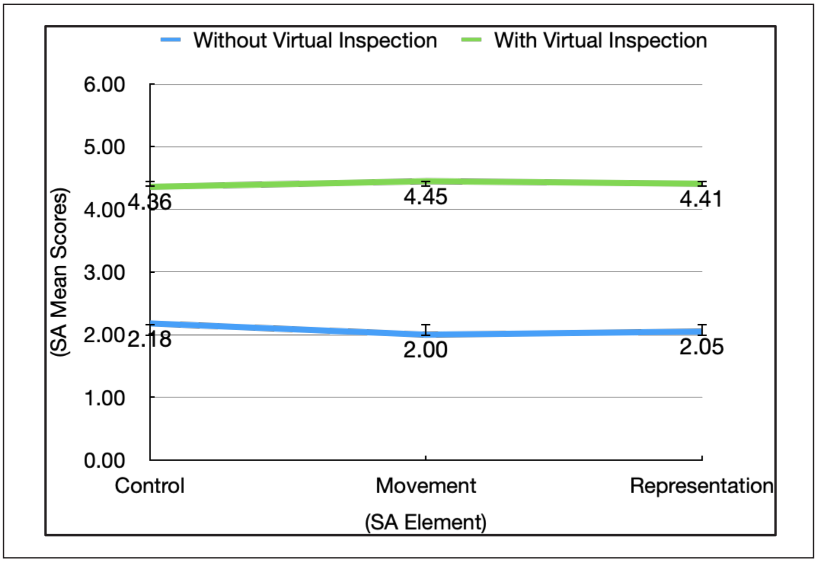


Table 2

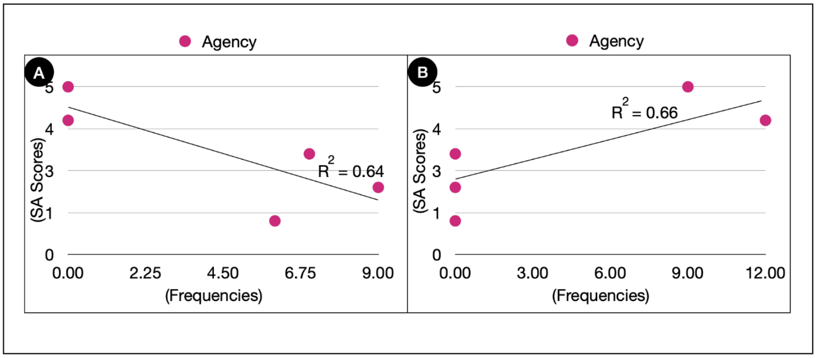
Overall Statistical Results

	p-Value	Mean (M)	Standard Deviation
Static Image	$p < 0.01$	2.08	0.67
Virtual Hand	$p < 0.01$	4.42	0.56
Diff		47%	

Figure 8 shows the correlation between SoA scores and their frequencies. Graph A indicates that conventional static images in online shopping applications had a strong negative correlation, which implied that the application with only static images provided less effective user interaction and perception. Meanwhile, the application with the calibrated interactive virtual inspection in Graph B showed a strong positive correlation, , indicating that the proposed method improved the SoA scores, i.e., increasing user interaction and perceived quality of an online application.

Figure 8

The Correlation between SoA Scores and Their Frequencies − Online Shopping Application with Only Static Images (A) and Online Shopping Application with Interactive Virtual Inspect Function (B)



From the analysis and results above, it can be concluded that the proposed interactive virtual inspection function with calibration method yielded a higher SoA, which allowed an application to improve its effectiveness on user interaction and perception in the digital platform. The users feel more control with the calibrated interactive virtual function as compared to only static images. The results proved that the proposed method successfully contributed to users' perception and interaction improvement. On the other hand, the proposed method showed the capability of building trust between humans and the digital domain, thus closing the gap between them.

CONCLUSION

This paper introduced a calibration mechanism to improve user perception and interaction in the digital domain. The mechanism is a calibration method that is based on the reciprocal scale factor from the virtual object to its real-life counterpart. Higher accuracy in VR allows users to interact in a more intuitive and non-intrusive manner. The study proposed a proof-of-concept interactive that incorporated a calibration mechanism. The prototype was tested on selected online shopping users. The study was based on SoA scores that focused on user perception and interaction with the prototype. The outcome indicated that the proposed method improved 47 percent in terms of user perception and interaction as compared to the conventional e-commerce application. It is important to note that the proposed method is not necessarily limited to e-commerce applications, but also in other domains such as medical, military, and education. The proposed method is naive yet effective and can be easily implemented in any digital field. This simple and effective calibration method can help to open a new and effective application outside of the e-commerce domain in the future.

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