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Incorporating Spatial-Visual Topology In Mobile Augmented Reality Application To Enhance Visual Realism

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ABSTRACT

Augmented Reality (AR) advancements on mobile devices which have seen now overgrowing, mirrored in the increased use of portable handheld devices referring to mobile phones and tablets in recent years which led to a sub-set of AR: mobile ARs (MAR). Nevertheless, in MAR, research is still lacking, especially research that focuses on implementing instructional based MAR application with appropriate degree of visual realism to support Spatial Visualization Ability (SVA). Thus, this paper provides an overview of implementation visual realism degree incorporate with Spatial-Visual Topology (SVT) in MAR application. First, we outline two main visual realism degree that applicable to implement in MAR application, which is Physical Realism (PR) and Functional Realism (FR). Then, we identify and applied appropriate SVT in each visual realism degree that offers important insights into the development of MAR application. We then discuss the advantages and drawbacks of each SVT and draw up an evaluation among the different visual realism degree and SVT. The paper provides an overview to propose new insight of design and developing instructional based MAR application to support SVA. Finally, the aim of this paper is to provide researchers with valuable understanding in implementation visual realism degree in MAR application and SVT concept to support SVA.

1. Introduction

AR's advancements on mobile devices are now overgrowing, mirrored in the increased use of portable computing around the world in recent years, which led to a sub-set of AR: mobile ARs (MAR) being developed. In order to ensure that the apps are more interactive, entertaining and educative, MAR apps were developed [1]. The research and development of MAR have further fuelled by the advances of the following three technologies; (a) development of specialized handheld and desktop AR applications (such as iPad, Mobile Phones, Google Glass and Microsoft Hololens) and versatile development kits (such as ARCore and ARKit), (b) improvements in handheld device performance and sensor integration, and (c) advancements in computer vision (CV) technologies [2]. MAR systems require the use of portable mobile interfaces for the user to communicate with digital information

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covering physical objects or surfaces in a normal and socially acceptable manner. Indeed, implementing the AR on mobile phones makes it the most convenient platform as most mobile devices are currently fitted with cameras. Mobile devices are nowadays equipped with high processing power, huge memory capacity, high resolution camera, rich multimedia features, and sensors. Along with this, the 5G technology with improved connectivity can caters the basic necessary hardware requirements for Augmented Reality on Mobile phones and provide [3]. Mobile Augmented Reality (MAR) experience. The MAR provides virtual information to the physical environment of a person without limiting the location of the individual to a specially equipped area. Ideally, users can work anywhere, prepare sufficient information to any desired environment. Thereby, the way to revolutionize on how information is presented to the people is secured [4].

Furthermore, possession of mobile devices has led to an increased interest in combining the advantages of smart computing and AR applications into learning sessions. Today, people were given communication, jobs, internet access, leisure and also learning and teaching in connection with the mainstream use and advent of mobile devices like smartphones and tablets a decade earlier. Installation of AR technologies on mobile devices has become feasible as the numerous developments in mobile technology (i.e., camera-built, cameras, virtual cloud computing, big data, crowd sourcing) have become possible [5]. Because of its mobile character, many MAR applications tend to run on mobile/wearable devices (e.g., computers, laptops, smart glasses, smartphones, tablets, and TVs).

2. Objectives

The objectives of this study are to provide an overview of the implementation of the Visual Realism degree incorporate with Spatial-Visual Topology (SVT) in MAR application and to design and develop the Mobile Augmented Reality Computer Organization (MARCO) to enhance learner Spatial Visualization Ability.

3. Visualization Learning

Many institutions of higher education are interested in developing new methods of simulation to enhance existing instructional frameworks. In that case, Augmented Reality (AR) is found to be one of the most exciting innovations [6,7]. The AR technologies also have the potential to be applied in pedagogical application and impose an impact on learning and education [8]. AR is a technology that consists of virtual images, 3D objects and other multimedia elements overlaid on top of the actual scene viewed by the user and computer-generated virtual scenes [9,8]. The AR is shown to improve the student's ability to visualize abstract and technical concepts [2]. This view is supported by Zheng *et al.,* [11] who believed that AR was a visualization tool that allows to investigate real-world systems with the combination of the leverage information.

The idea behind the visualization learning strategy is to enable students to perceive information that do not directly applicable using conventional or normal approaches. However, improving student visualization will help users to carry out daily real-world tasks and events, such as installing a computer system [12]. In this visualization learning strategy, students require to select a lesson in AR learning environment and the matching learning tools for presenting the visual material. Student needs to follow the lesson and complete the task given as illustrated in Figure 1.

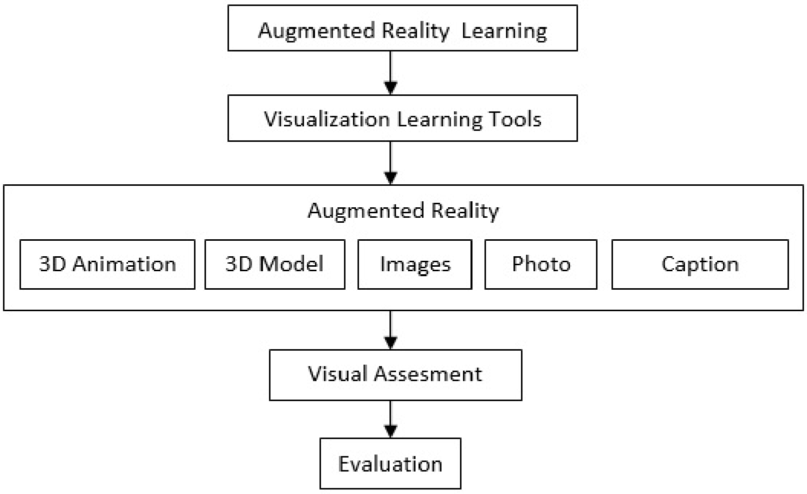

Fig. 1. Visualization learning strategy

4. Spatial Ability

The numerous researchers who studying this ability has contributed to several definitions of spatial ability. Gardner [13] defined Spatial Ability (SA) as the ability to precisely discern the visual environment, transform and alter one's initial observations and recreate the characteristics of one's visual experience, even in the absence of physical stimuli. According to Gardner [13], the SA deals with visual perception, mental images, sharp insight, and nature awareness. Thurstone & Thurstone [14] listed SA as one of the strongest mental abilities, generally defined as the ability to manipulate forms, weights, and distances mentally. Chen *et al.,* [15] summarizes the SVA as the ability to visualize what an unusual form would look like if it were spatially rotated, or the ability to discern the relationship between shapes and objects. McGee [16] describes SA as the ability to form secure and reliable mental representations of spatial information for use in three-dimensional application. Kwiatek *et al.,* [17] defines SA as one of the measurements used to verify the ability of learners to mentally reorganize or manipulate the components of the visual stimulus which involves identifying, maintaining, and retrieving configurations when the figure or part of the character has moved.

5. Spatial Visualtization Ability

Specific to the study, the definition reflects the types of spatial skills needed in solving visualization problems in learning process, which is the Spatial Visualization Ability (SVA). SVA is one of the SA components. SVA is the ability to manipulate complex spatial information by many steps. [19] summarized the effectiveness of SVA involving review of task criteria and rapid implementation of solution procedures. It is found that three dimensional (3D) spatial representations are the most widely used form of descriptions in any physical component problem that is the capacity of learners to transform mentally such as rotate, reflect, fold, or unfold, synthesize visually presented figures [16]. The phrase 3D spatial representation is defined as a representation of space showing three combinations of dimensions in a figure (height/width/depth). Besides, according to Kwiatek *et al.,* [17], SVA is also the most important part of spatial cognition to the task of the assemblies, as it depends on the process of manipulating 3D objects in one's mind and being able to analyze design information to visualize the required constructions. According to Zollmann *et al.,* [19], SVA has a learning effect described as being able to picture 3D shapes in the mind's eye. SVA can be categorized into 2 levels which is high SVA and low SVA. Table 1 outlines the differences in the characteristics between high and low SVA learners based on the research done by Hindal [20], Eswaran *et al.,* [21] and A Shaaban *et al.,* [23].

Table 1
High and low SVA learner's characteristics [22]

High Spatial Visualization Ability (HSVA)	Low Spatial Visualization Ability (LSVA)
Non-Sequential learner	Sequential learner. Step-by-step learner
See the big picture first before they learn the details	See segment by segment first before they learn the details
Able to compose significant amounts of information from different domains, but they often miss the details	Impossible to compose large amounts of information from different domains, but meticulous with the details
Organizationally impaired learner	Well organized learners
Unconscious about time. Perform better in untimed situations	Conscious about time

Studies also have shown that SVA is related to task comprehension. Examples of these studies include by in laptop maintenance, in computer hardware, in motherboard assembly, in Information, Communication Technology (ICT) course and in computer programming [23-29] The literature also shows that SVA skills can be improved by teaching and learning [31-33]. In short, there are differences in the exact definition and measures of SVA. However, when it involves learning with physical components, assembly processes and practical tasks, McGee's [16] description is the most commonly used definition for spatial ability, probably because spatial problem-solving in CSO often demand the executions of mental transformation processes such as the mental rotation process (manipulate, rotate, twist, zooming or invert) [15,22].

6. Spatial Visualization Ability and MAR

There has been a significant relationship between learning mode and spatial visualization ability. In Hindal's [20] research, learning with MAR significantly improved spatial skills. Further study reveals that MAR is an effective and useful resource for creating spatial visualization capabilities and also have shown that HSVA learner benefits more from MAR visualization-based training [39]. Nonetheless, Sugara *et al.,* [33] concluded that LSVA learners are more positively affected by MAR visualization-based training but with specific assistance as they have troubles in mentally visualizing them.

[6] explored how MAR affects the learners understanding of spatial ability. Boonbrahm *et al.,* [34] found that MAR helps students to easily understand and learn through improved visual in a short time. [6] reported that MAR emphasis the following distinctive advantages for enhancing spatial ability

i. Provided with information related to a real-world place while simultaneously considering the object of interest
ii. Enable complex procedures transparent and effective ways to show relationships to the learners.
iii. Object modelling application that allows students to receive immediate visual feedback on how a given object would look in a different setting and interaction between objects; and
iv. Individual skill training in specific tasks, for example assembly task used in computer build, operations and maintenance.

MAR offers as a capable technology to improve students' spatial ability due to its media attributes (visual rotating, zooming into details, animations, highlighting aspects, etc.) and immersive learning environment [40]. Moreover, MAR is an effective platform for enhancing and conceivably improving the spatial visualization ability by administering proper treatment sessions and reliable instructional application [40].

Spatial visualization abilities can be improved and trained by MAR application with systematic treatment and instructional [39]. Several studies have shown the usefulness of MAR in training spatial visualization ability [38,40]. According to Tuker [40], in order to carry out practical training in the field of spatial visualization ability, all instructional application must follow a systematic approach based on the type of skills and knowledge to be learned. Applications of MAR, which focus on the instruction of the spatial visualization skills, can be classified as instructional application. According to Batool [37], an instructional application can be drawn up in five different categories

i. Drill and Practice Software (DPS) for skill development, which allows students to solve a wide range of problems or to answer questions and receive feedback on the accuracy of their responses;
ii. Tutorial Software (TS) which aims to provide education on its own without the existence of a teacher. These include the initial teaching material that the student needs to learn. These are self-driven software, and the user is able to adjust the speed of the instruction to be given;
iii. Simulation Software, (SS) Current machine or environment technical models which demonstrate how the system works. The students can gain real-world experience by using simulations. This application focuses on teaching about the system itself by allowing students to study scenarios generated by the software or manually by a teacher who watches the student during the simulation process, rather than general problem-solving approaches;
iv. Instructional Games (IG) Increase learners ' motivation by incorporating gamification, game elements, rules, competition and entertainment factors in learning and simulation activities; and
v. Problem-Solving Software (PSS) Aimed at achieving the learner's analytical thinking, in which knowledge and skills are necessary to solve a particular problem.

Considering spatial visualization ability aspect is important in learning CSO, the design and development of MARCO were based on TS and SS approaches and emphasize on 3D model, animations graphics and simulations. TS were implemented in order to give freedom to the learner while exploring the application by themselves while SS will guide and assist the learner in understanding the concept of CSO and also to experience the realism simulations on assembling computer hardware and components [37,39].

7. Visual Realism

Several methods have been suggested to improve the accuracy of AR encounters in literature. Operating with virtual objects in augmented reality, typically had no sense of realism as performing with the actual experiment, as there were no physical properties in the virtual model. The virtual analysis will be the same as the actual experiment by incorporating physics such as volume shapes, depth, size and projected the coexistence of virtual and real objects in the same space [35]. Skulmowski [41] has found that while realistic experiences allow the user to engage and develop a sense of being in it, higher abstraction stimulates the senses of the user to develop a greater understanding of being anywhere in the world. The goal of AR is to produce realistic representations of a simulated environment in a way that conveys the same experience as a real scene and draws users' interest [41]. In order to engage learners, different AR application in education require practical interactions between real-world objects or among users and virtual objects. The rendering of real-life graphic in situations where enhancement objects are used to give instructions is preferred as the enhancement is supposed to draw attention as well as enables the user to focus on more efficient visualization information to be carried out [27]. From the learner standpoint, AR offers helpful instructions in the real environment and facilitates quick collection and submission of crucial information to support user assembly tasks [23]. Sirakaya & Cakmak [25] proposed the AR application for computer hardware assembly. Researchers have also indicated that learners will increase their motivation to learn and develop their practical school practices by implementing AR [36].

Ferwerda [42] states that three ranges of graphic realism vary in the degree of visual coding at which realism is established

i. Physical Realism - Synthesis of the physical image will render a visual stimulus similar to the stimulus of a real scene. The picture must include accurate descriptions of the scene's forms, textures, and lighting properties.
ii. Photorealism - It is noteworthy that an image is still capable of eliciting the same emotional response and is considered to be authentic, a form so distinct from a real scene. Image recognition systems can be more mechanically oriented and can only simulate images as correctly as display technology can display or as interpreted by human visuals.
iii. Functional realism – non-photographic images can still provide the same visual information as an actual scene. Knowledge here implies awareness of the related properties of objects at a point, such as their shapes, heights, positions, movements, and materials, allowing an observer to make fair judgments and make visual observations.

In the same way, much of these ranges of graphics realism applied in MARCO visual content. In this study, MARCO visual content aims to provide realism in AR experience for learners. Correctly, MARCO used two ranges of realism, namely: physical realism and functional realism. This statement is supported by Skulmowski [41], who claims that physical realism helps involve learners, increase visual perception and gives a feeling of being in the virtual environment. Moreover, as noted by Boonbrahm *et al.,* [34], physical realism is used to emphasis augmentation and preferable in which AR is used to give instruction where it enables better visualization as the learners can concentrate on the visual content to be conveyed. Moreover, it supports the understanding of 3D shapes. Implementing realistic and interactive AR content merging with real environment genuinely give enjoyment experience to learners [35]. As the earlier study proves that spatial visualization abilities play an important role in assembling tasks and understanding visual content enhance by visual realism. AR technology has vast potential and numerous educational benefits as AR features can motivate and engage learners with different spatial visualization abilities in process learning and to support develop their visualization skills [10].

8. Spatial Visual Topology

Given that the visual-spatial feature is at the heart of AR technologies, it should be centered on the classical theory of spatial cognition [43]. There are two typology types which support the theory of spatial cognition which is Visual-spatial knowledge and Visual-spatial space topology.

Visual-Spatial Knowledge Topology

i. Procedural knowledge - This helps learners to navigate in a geographical area and provides the basis for navigation.
ii. Declarative knowledge – Allows students to determine the substantial facts about and objects within geographical space
iii. Configurational knowledge – Refers to geographical spatial knowledge, commonly found to be map-based with information about distances and relationships between spatial objects or entities and relative positions, orientation.

Visual-Spatial Space Topology

i. Haptic space - The visual –spatial knowledge that is related to the motion of the objects or body.
ii. Pictorial space - The understanding of space which is based on the visual context
iii. Trans perceptual space - The visual-spatial knowledge that consists of several sources of information or experience at the certain time. [43].

AR visualization is considered to be the incorporation of structural or configuration of information into the visual-spatial knowledge topology [43]. It could be procedural as well since AR allows a 3D view and enables the user to experience it in a virtual environment, as the 3D models are rotating, zooming or animated. It could also be configurational because of the interactive modalities where a user holds a physical object and views the entire geographical space from the perspective of his own. The perceptual engagement by which spatial awareness is interpreted, checked, triangulated and implemented will improve the better sense of 3D content for AR users. Whereas, based on the visual-spatial space topology, AR visualization can enclose both haptic and pictorial spaces where physical action and visual input are implemented to gain visual-spatial knowledge correspondingly. This classic theory of spatial cognition shows that physical activity is not only manipulation of situations in particular, but also strongly linked to the first form of visual-spatial knowledge topology which is procedural knowledge [43]. Additionally, the integration of procedural knowledge and manipulation of situation could significantly improve the visual perception and spatial information [43]. Hence, AR visualization shows its advantages of precise cognition and notion by utilizing haptic visual-spatial spaces and strong pictorial gained through engagement and stimulation [21]. This theory of spatial cognition provides essential insight through the development of Mobile Augmented Reality for Computer Organization (MARCO). As a result, AR visualization has been recommended as an effective spatial visualization tool for users to provide manipulation inputs associated with spatial and visual indication due to sensorimotor feedback while also essential to guide tasks assembling due to the spatial and visual indication set in daily user environments [21].

9. Proposed MAR Application for Spatial Ability: MARCO

MARCO is a mobile augmented based application for learning computer assembly, specifically designed to support learners with different SVA. The designed MARCO application is based on the Android software development kit (SDK). The main software components are an interface/view component, an application controller, a rendering component, and a tracking component. The MARCO interface is integrated and compiled using Android SDK in Unity 3D software. The rendering module, which is used to recognize, process images is based on Unity 3D real time rendering engine.

The main function of the MARCO interface component is to uphold procedures for all interface processing, as well as for the AR view camera. The AR view camera controller receives events when the user interacts with a marker or invokes a gesture. Each established interaction event is processed and dispatched to the controller. The controller component main task is to controls the appearance/disappearance of all selected 3D models that need to be displayed for a given task. Every 3D model is assigned with unique ID which is associated with a marker ID. Controller component will maintain a list with all association ID and enable/disable 3D model visibility when the related ID are match or mismatch. Next component is tracking component. Marker-based MAR relies on continuous object tracking which is marker. Tracking component detects images from cell phones or tablets through AR view camera, analyzing them to identify markers and then calculating the location and orientation of each marker. The marker ID is then sent to the control component and the marker position is sent to the rendering component. The last component of the MARCO is rendering component. This component generates the AR view, which incorporates the virtual 3D objects. All 3D objects are rendered, which is superimposed on camera view of a mobile phone. Figure 2 shows an overview of the application architecture of MARCO including all subcomponents and their functions.

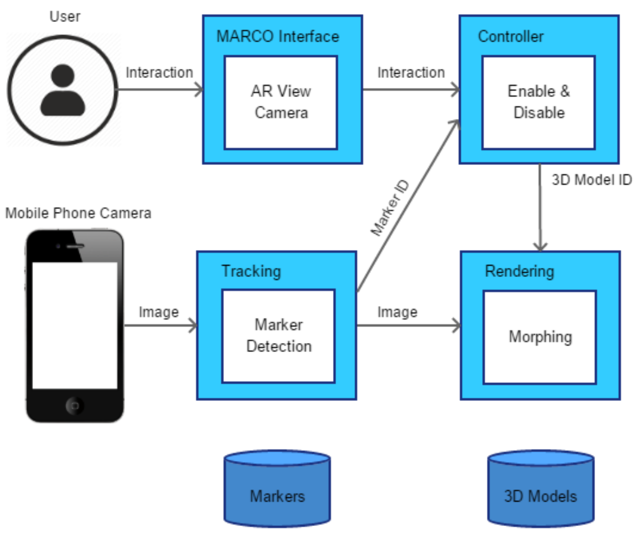

Fig. 2. Application architecture of MARCO

MARCO consists of two modes. The first mode is MARCO-FR (Functional Realism) and the second modes is MARCO-PR (Physical Realism). In the MARCO development process, concept analysis was used for viewing concept and relationships of all MARCO main contents and components. Figure 3 shows the flowchart of the MARCO content for both modes. It is a detail representation of the content flow of MARCO application.

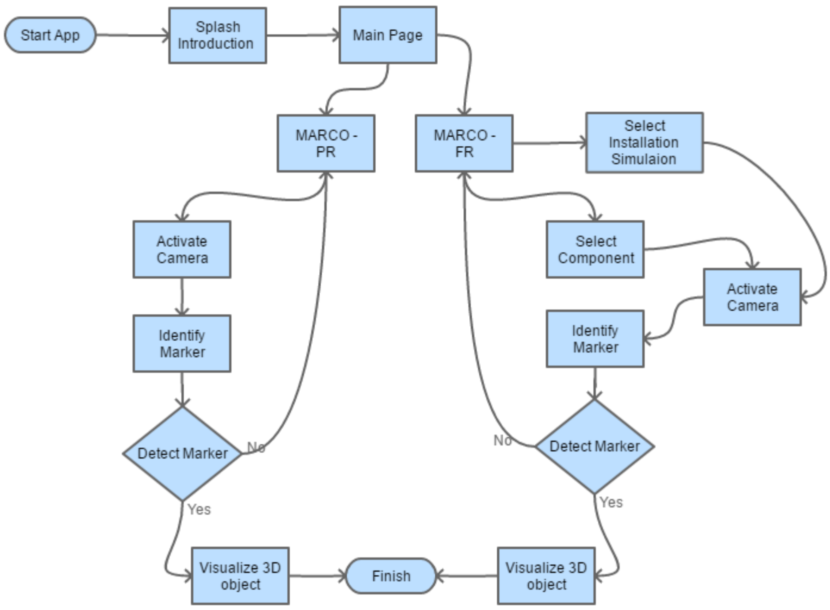

Fig. 3. Application architecture of MARCO

Spatial Visual Topology (2021) offers important insights into the development of MARCO modes which is support both high and low SVA learners. Table 2 summarizes MARCO modes design specifications guided by Spatial Visual Topology and relationship with SVA where Visual-Spatial Configurational Knowledge (VSCK) applied in MARCO-FR and Visual-Spatial Procedural Knowledge (VSPK) applied in MARCO-PR. In the same way AR visualization can enclose both Visual-Spatial Haptic Space and Visual-Spatial Pictorial Space (VSHS & VSPS) are implemented to gain visual-spatial knowledge consistently. To sum up, the framework by Purwitasari *et al.,* [44] has been adopted to illustrate the visualization process as shown in Figure 4.

In addition, based on Table 2, MARCO-PR implemented Procedural Knowledge to stimulated High SVA learner as it concerned on user control of the actual component (PC Parts) as well as assisted by additional visual information (sound, 3D images, animation and text). It will help the student to identify computer hardware and its function. MARCO-PR mode will provide details visual simulation (Haptic & Pictorial space) as the real hardware on every hardware component. Meanwhile, in MARCO-FR implemented Configurational Knowledge to assisted Low SVA learner as it concerned on 3D model and simulation (Haptic & Pictorial space) projected by augmented including other digital visual information (sound, 3D images, animation and text) a as a main visual aid to assisted Low SVA learner to identify computer hardware.

Table 2
MARCO treatment modes design specifications

Item	Spatial Cognition Theory Topology	MARCO FR	MARCO PR	High SVA	Low SVA
1	Visual-spatial knowledge topology - *Procedural Knowledge*	√			√
2	Visual-spatial knowledge topology -*Configurational knowledge*		√	√	
3	Visual-spatial spaces topology – *Haptic Space*	√	√	√	√
4	Visual-spatial spaces topology – *Pictorial Space*	√	√	√	√

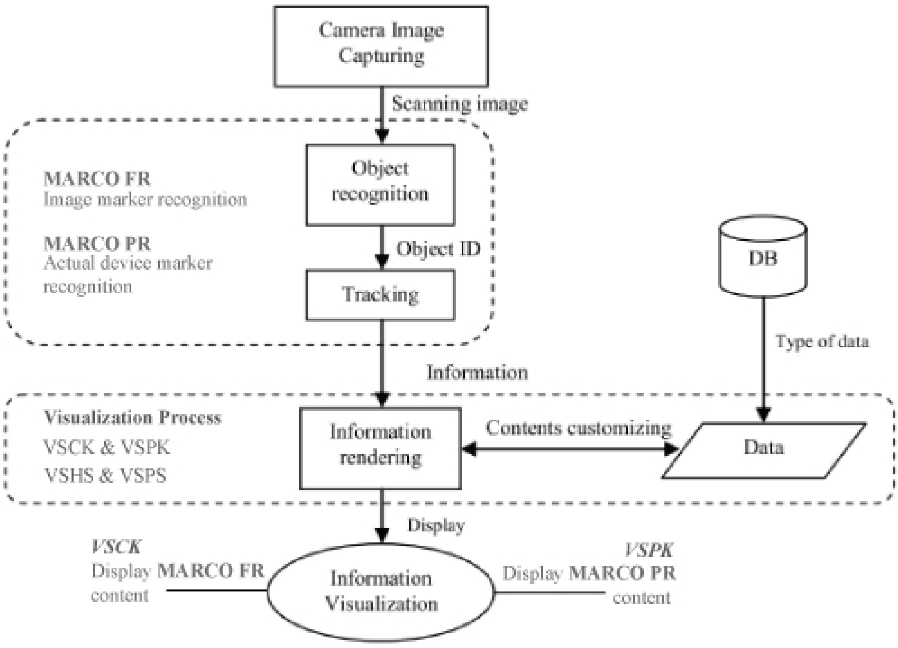

Fig. 4. AR visualization process [44]

Figure 5 and Figure 6 showed the approach of physical and functional realism. Physical realism approach contains additional information (i.e.: 3D model, animation, text) overlay on top of actual objects (i.e.: PC Motherboard) and act as a marker when it triggered while in functional realism approach, 3D models and simulation with additional information are triggered by using image assign as a marker.

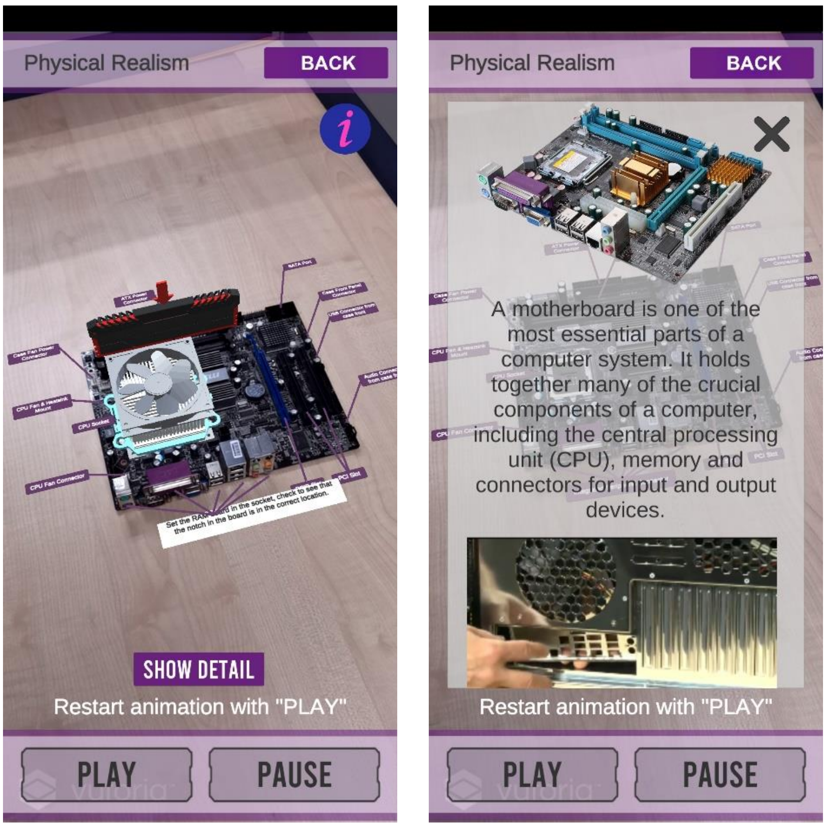

Fig. 5. Physical realism approach

Fig. 6. Functional realism approach and marker

10. Result and Discussion

The purpose of this research is examining the effects of visual realism using MARCO application on learners with different Spatial Visual Ability (SVA). The research design employed in this research was a control group of quasi-experimental 2 x 2 factorial design. Two modes of MARCO application were use in this research: Functional Realism (MARCO-FR) and MARCO Physical Realism (MARCO-PR) with Spatial Visual Ability (SVA) as a moderating variable. Around 200 students were involved. Result from this research mainly those with HSVA have shown significantly improvement and positive results when using MARCO-FR. Result from this research showing a positive response to both high and low SVA learners using MARCO application. Nevertheless, the high SVA learners scored slightly greater than the low SVA learners in both MARCO modes. There was a significant difference in learning comprehension between high SVA and low SVA learners when employing the two MARCO modes. This shows that both MARCO modes contribute positive learning comprehension for high SVA learners. These results also show that both high and low SVA learners comprehend better from MARCO-FR modes regardless of their SVA level. The use of various multimedia representations of contents (text caption, videos, audios, sound effects, images, 3D object and simulation) as well as learners enable to manipulate 3D contents representations (repeating, rotating and zooming) in MARCO-FR, offers various opportunities to cater to the different level of [45]. This augmented reality visualization learning approach allows instructional elements to be visual presented by combining ideas and concepts with graphic presentation to better understand on how to retain information [46].

11. Conclusion

This study discusses the development of Visual Realism Based guided by the Visual-Spatial Topology in the process of developing MARCO modes as well as to assist both HSVA and LSVA leaners.

In conclusion, the development of MARCO modes was discussed in detail due to its strengths and characteristics that could help in overcoming some issues faced by visual learners. The work presented in this paper can be considered as a significant positive improved in visual realism for domains such as mobile application and instructional learning. It facilitates users learning improving spatial visual ability and ensures improved recognition of visual object parts. However, it still faces constraints in designing realistic 3D objects and degree of details. The drawbacks of this Spatial Visual Topology need to be explored in depth to find potential approach to implement into real AR application. For future study, our aim is to discover multiple type of Visual-Spatial Topology and degree of realism for the manipulation of various 3D objects for functional use in real world application and case, especially in real world assembly tasks.

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