Occlusion in Augmented Reality

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***Abstract*—Augmented reality in video-based display simply overlay virtual objects on real environment. In many cases this does not represent the actual situation in AR scene. When a real object supposes to occlude a virtual object, the augmented image may cause confusion in users' perception. This incorrect display contributes to misconceptions and wrong operations of task amongst users. The scenario of occlusion in AR application is discussed in this paper. Next, the main method used by other researchers to resolve occlusion problem was discussed. This is followed by a discussion about dependency factors and characteristics that influence the selection of occlusion handling approach and a comparison between a model-based and depth-based approach. Finally, a conclusion and proposed work are presented.**

Keywords-augmented reality; occlusion

I. INTRODUCTION

Augmented reality (AR) is a new way of human and computer interacts [1], [2]. It is a medium which allows a 2D and/or 3D computer graphics to be superimposed with the real scenes in real-time [3], [4]. It offers a significant potential in many applications such as industrial, medical, education and many other disciplines. According to [5], in order for AR to become fully accepted, the real and virtual objects within the user's environment must be seamlessly merged where the real and virtual objects must interact realistically. One of the effects such as shadows, illumination and reflection that we see in reality should also be seen realistic in AR is occlusion.

Occlusion occurs when an object closer to the viewer obscures the view of objects further away along the line-of-sight [5]. In AR, occlusion occurs in video-based display such as monitor-based or video-see-through display technologies. In augmented surfaces, video-based AR will simply overlay a virtual object on scene video. This makes real objects always being occluded by virtual ones [6], [7]. In certain application this situation does not usually occur. Sometimes, the object being tracked (virtual object) moves behind the occluding objects (real object) which may cause an incorrect occlusion. According to [8], the errors of occlusion easily ruin the feeling of presence the user might otherwise experience. Research on solving the problem of occlusion have been done in [5], [18], [31] for model-based approach and [5], [29], [34], [35] for depth-based approach.

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The rest of the paper is organized as follows. In Section 2, we briefly describe the concept of AR. Section 3 explain about occlusion concept, occlusion effects and occlusion resolving techniques in AR. Section 4 discuss a research structure on AR occlusion, followed by factors that influence a selection of occlusion handling approach and a comparison between a model-based and depth-based approach is made. In Section 5, a proposed work is discussed. Finally, in Section 6 the conclusion and future work is presented.

II. AUGMENTED REALITY

Augmented reality (AR) is a technology that concurrently allows visualization of both virtual and real objects in physical environment. The goal of AR is to enhance a user's performance in handling task and increase the perception of the surrounding world with a seamless integration between the real world and the virtual augmentation [1], [3], [9]. The virtual objects should ideally appear in such a way that user and real objects can interact in a natural manner by the feeling of working in a single real environment [9].

In AR interface, it brings the computer out of the desktop environment and incorporates the computer into reality of the user. The user can then interact with the real world in a natural way, with the computer providing a graphical information and assistance to help a user performs real-world tasks [3], [5].

A. *Applications and Advantages*

AR has many potential applications. For example in medical domain, AR has been used as a visualization and training aid tool for surgery. Surgeons can detect some features with the naked eye that they cannot see in MRI or CT scans which guide precision tasks, such as displaying where to drill a hole into the skull for brain surgery or where to perform a needle biopsy of a tiny tumor [3], [9], [33].

AR might also be helpful for maintenance and repair task. AR technologies can provide annotated and graphics instruction superimposed in real-time on the technician's field of view. This helps the technician to concentrate on the task at hand without having to change head or body position to receive the next set of instruction. Thus, AR as an instructional medium reduced the overhead of attention switching between repair manuals and the task [10], [11].

Other application of AR is in manufacturing. A system that recognizes electronic components can speed up the building of a circuit on a printed circuit board by telling the human where to insert a component. This indirectly includes training the operator to perform a complex 3D task which can normally be difficult and costly [12]. Therefore, in [13] AR technology is described as a useful visualization technique which has a huge potential for a wide range of areas.

B. Issues in AR

For AR technology to be fully accepted, both real and virtual objects must be seamlessly merged in a scene and gives the same effects as a real environment. [10] highlighted three main constraints that exist in AR to make AR look realistic and practical. This problem includes errors in tracking, accurate calibration and system display. All these requirements have to be satisfied so that user will not feel distracted while interacting with this system.

Accurate calibration is important especially with 3D display systems because when rendering virtual objects above real environment they have to match the perspective and depth of the real scene. User would certainly get very distracted if virtual objects are floating in front of real objects but they suppose feel it to be further away. These faulty camera parameters would cause occlusion errors in AR display. Other than occlusion errors, effects that we see in reality and therefore expected in AR display include shadows, diffuse, specular, and internal reflections, refraction, and color bleeding [5]. This is because visual interactions between real and virtual objects are based on the inter-reflections, absorption, and redirection of light emitted from and incident on these objects. However, [8] considers the problem of occlusion is one of the visual effects that need attention from researchers.

III. Occlusion in AR

Occlusion occurs when the merging of virtual and real objects involves the obscuring part of objects. Occlusion may occur in three situations i.e. an occlusion only between real objects, an occlusion between real and virtual objects, or occlusion only between virtual objects. The possible techniques used to resolve occlusion in these situations were discussed in [14]. However, the problem of occlusion in AR involves occlusion between real and virtual objects.

Occlusion problem is treated differently depending on the AR display system selection i.e. either video see-through HMD; semi-transparent HMD; or; screen-based or back-projection environment. Handling occlusion using a different mechanism for the display system are discussed in more detail in [37].

This paper will only discuss the problem of visual occlusion involving real and virtual objects using video-based AR display system.

A. Occlusion Concept

Generally, in video-based AR system, all the pixel elements of the graphical virtual elements are drawn over the camera image thus completely occlude the real environment [1], [6], [15], [16], [17][18]. This results in real objects always being occluded by virtual ones [6]. In other words, each virtual object combined with the real environment will always be in front of the real object or is closest to users' eyes. In most cases, the circumstances in which virtual objects are always in front of real objects do not always happen. Sometimes when the virtual object is behind of the real object, it should seem realistic by displaying an accurate and correct position of all objects. If this does not happen, then the problem of occlusion has occurred. In dynamic views such as assembly operations for example, the problem of occlusion in AR scene is unavoidable since users always pay more attention to the assembly relational region rather than the video image [1], [19], [21].

B. Effects of Occlusion

In video-based AR system virtual objects are simply overlaid in the real scene. When a real object is supposed to occlude a virtual object, the augmented image may cause confusion in users' perception. Users will have an illusion that the virtual object occludes the real object. Incorrect display on this situation may contribute to misconceptions of spatial properties by the user, incorrect operations of task when trying to grab an object, thus would also increase eyestrain and the probability of motion sickness [7], [15], [20], [22], [23]. These problems can affect the experience which should be more meaningful [8].

Until now, many researchers aimed at solving the incorrect occlusion problem by analyzing various tracking methods or by integrating vision-based methods with other sensors [13]. This is a critical challenge in AR visualization which is to ensure virtual and real objects displayed must convinced the illusion of their co-existence and interaction.

For example, [24] applied a scenario of augmentation between scuba tanks suit and human body as shown in Figure 1. Figure 1(b) shows a snapshot of incorrect occlusion when the virtual scuba suit is naively added on the original image of 1(a). Figure 1(c) shows a corrected occlusion with corrected position of tank and scuba suit. This incorrect occlusion ruins the illusion of coexistence and may increase eyes- strain.

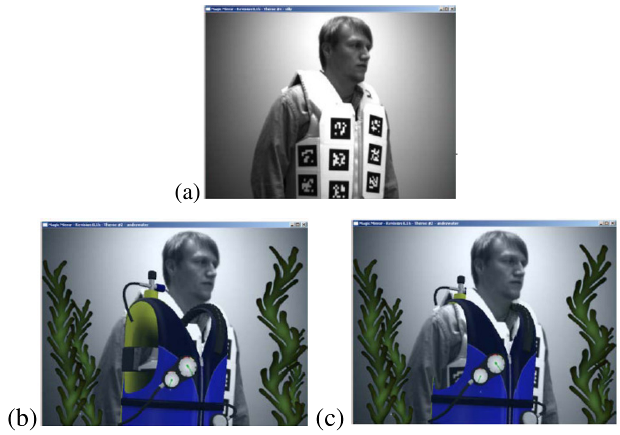

Figure 1: (a) A snapshot of original image; (b) Incorrect occlusion; (c) Corrected occlusion *(Source: Fiala, M., 2006)*

A specialized occlusion handling method was applied for medical AR [25], [26]. Figure 2 illustrates a typical case of ambiguous AR image due to the lack of occlusion handling. In Figure 2(a) & 2(b), the virtual graphical model of a tracked tool (surgical equipment) is overlaid over the camera image. In Figure 2(a) the real tool is located in front of a plastic skull. Hence, the resulting image shows a correct position of the tracked tool because the virtual tool occludes the plastic skull. By contrast, in Figure 2(b) the real instrument is behind the skull. Therefore, the smaller virtual tracked tool is supposed to be rendered behind the skull phantom but it appears to occlude the plastic skull. In Figure 2(c) the corrected occlusion of smaller tracked tool behind a plastic skull is displayed. Solving this problem enables user to easily determine whether a graphical object is in front of or behind the patient. In medical application, handling occlusion is an important aspect because incorrect occlusion may result in wrong operation of task, thus inviting danger to patient if applied to real application such as surgical operation.

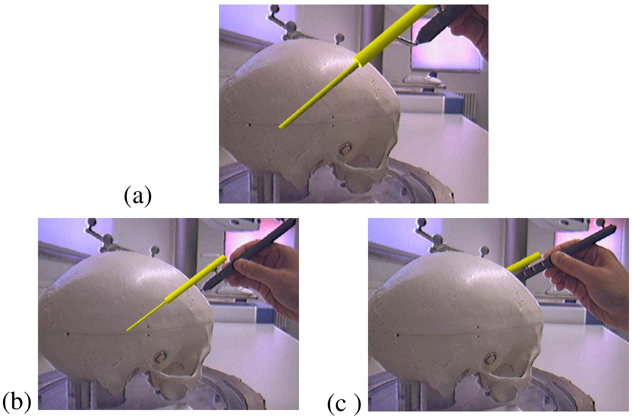

Figure 2: A relation between (a) Tracked tool in front of plastic skull; (b)Tracked tool behind plastic skull (Incorrect occlusion) ; and (c) Corrected occlusion *(Source: Fischer, et. al. 2004; 2007)*

C. *Resolving Occlusion*

Several researchers have worked on the detection and handling of various occlusion problems in AR application. Occlusion can be categorized by what kind of object is hidden by what kind of 'occluder' [14]. The most important issues in resolving occlusion in AR scene is occlusion between virtual and real objects.

Occlusion problems are resolved by two categories, which is occlusion detection and occlusion handling. Occlusion detection is a technique used to decide whether some objects overlap or not between the virtual and real objects. In occlusion handling, if overlapping is detected, the system need to optimize rendering accordingly by not drawing what is not visible [8].

There are two approaches mainly used to overcome this problem, namely model-based and depth-based approach.

1) Model-based Approach

Model-based approach typically requires only one camera [5], [23]. But there are also studies that require more than one camera but the camera serves as a performance camera [31]. There are also studies in this approach which integrate other hardware such as a tracker [26]. Most of the studies on this approach [5], [23], [36] took the 3D modeling of the real objects directly from existing resources or re-modeled it using any 3D software, while some studies experimented with 3D reconstruction method for the purpose of re-modeling the actual object [31].

Model-based approach is used when the actual environment is easy and completely understood where complete 3D models of real objects can be obtained. The process of dealing with occlusion depends on the information of data model from both virtual and real objects, as in [5] and [23]. Since all the available data including the depth of points (pixels) can be obtained from a 3D graphics model this algorithm can be generated more quickly. However, this method requires modeling the real environment first. Thus making this method suitable only for a simple and not too complex environment [16].

[5] has developed the GRASP system, a system for interior design applications. In this system he proposed two methods for static scene in real-time occlusion handling which is model-based and depth-based approaches. For model-based approach, first a complete model of real objects are required beforehand. In this approach, he combined a magnetic tracking system for tracking purposes. An automatic camera calibration step is required in this system. This is followed by the registration process of identified geometric model at the same location and orientation of real objects in live video. Finally, the occlusion handling step is used to produce the illusion that the real object is occluding the virtual one.

AR image guided surgical system (ARGUS) has been implemented in medical applications by [18]. This system was used to assist surgical procedures by combining medical related virtual image into live video. In this system, occlusion detection between real and virtual objects has been introduced. He uses a model-based approach to develop occlusion detection algorithm. This algorithm does not require any previous knowledge about the objects that are occluded, but only depends on the texture of the polygon graphical model. This study made the assumption that when a real object can be detected in front of a virtual object, then it is in front of all other virtual objects. However, there are many weaknesses in this study. Among them, the algorithm is not suitable for other applications because it is designed specifically for applications involving the interaction of AR environment using only hand or pointing devices. This algorithm is also not suitable for application in real time.

Occlusion detection task in AR system is very challenging [8]. Thus, some researchers had integrated a 'painters' algorithm and some particular rendering method so that the detection of occlusion becomes more practical. [23] for example, has developed a collaborative virtual environment system (i.e Studierstube) that allows multiple collaborating users to simultaneously study 3D scientific visualization in a 'study rooms'. In this study, he integrates a z-buffering techniques for model-based approach to address the problem of occlusion. This approach requires prior information on the

3D geometric model (which already exist - such as the CAD model). This method is significantly faster than depth-based approach and occlusion problems can be handle automatically. However, this approach is only appropriate when involves a simple and static environment.

In implementation of scenic art AR project, [31] used a model-based approach which involves a movable and deformable object. This method relies on a single main camera for tracking purposes and requires that the real objects be located within an approximate bounding volume. By using a background subtraction algorithm, the silhouette of the object is then carved into this volume by using an additional camera (which also known as performance camera) and its 3D information is used for handling occlusions. This process is also known as 3D reconstruction (bounding volume approach). The advantages of the bounding volume approach is that, it is insensitive to jitter and positioning errors for the real objects. Furthermore, this approach is able to handle a movable and deformations in the structure of the objects. However, the main limitation in this approach is that, the viewpoint and lighting must remain fixed due to the background segmentation technique used. To make sure that the segmentation algorithm is successful, the objects must have a color and texture. Else, there might be holes in the bounding volume which would allow the virtual object to be seen through the real one.

Overall it can be concluded that this approach essentially requires a computer graphic model of real objects obtained in advance. Various efforts were used to obtain a graphical model, either directly obtained from existing CAD software, by developing a new model from any 3D software or by using 3D reconstruction technique. In this approach, after the completed graphical model of the real object is obtained, then the object will be treat as a virtual object for the next step. Hence the attempt to make the interaction of occlusion is further addressed as the relationship between only virtual objects. The advantages of graphics hardware through z-buffering techniques are often used. This technique can be seen more quickly than other technique which requires 3D reconstruction. But often there is a problem when it comes to the need of modeling complex objects. The more complex an environment is, interactive processing is becoming increasingly difficult thus limiting the broader application. This approach is more appropriate for a simple environment and does not involve complex real objects. The model-based approach by using 3D reconstruction requires an accuracy of the reconstructed 3D objects. The significant error which gives an impact on the operating results of occlusion can be seen. However, the advantage of this method is that it is able to handle occlusion problems which involve movable and deformable objects.

2) Depth-based Approach

Depth-based approach tries to resolve occlusion in AR for unknown real object which is also called dynamic occlusion handling [25]. In this situation, nothing is known about the shape, size or position of an occluding object.

Depth-based occlusion has been studied with various different techniques. This approach involves the images captured from 2 or more cameras. Using–2 cameras (also known as *stereo cameras*) the depth image can be acquired from the object shape such as from stereo images, motion sequences, object shading, shadow casting, highlights & gloss, and more [28].

Depth sensing can also be accomplished with monocular vision using one camera [32]. The trick is in using multi-focused images from the same viewpoint. With just three unfocused images it is possible to extract the depth information from the blurriness of individual pixels. This approach does not require geometric descriptions of real objects in the environment. Some image processing and computer vision techniques are used in order to detect occlusion.

[34] presented a video see-through AR system that is capable of resolving occlusion between real and virtual objects in a dynamic environment. Their system can run nearly in real-time by using 'depth-from-stereo' algorithm. This requires two cameras aligned together such that epipolar lines are parallel to a scan-lines. This system requires no camera calibration. However, the use of stereo cameras caused their method to have difficulties in computing the depth for featureless (flat & light, no texture and horizontal) image. Thus, although the depth of the image can be generated interactively the result still ended with unsatisfactory results (faster but less accurate).

The depth-based approach in [5] is based on the depth information of images from the rendered viewpoint. The depth information is obtained from the stereoscopic vision and processed directly into the depth buffer for occlusion handling. The advantage of this method is that, it does not require the whole scene to be computed but a depth map along the rendered viewpoint. This method is also suitable for the static scene in complex environment. However, the depth map highly depends on the position and orientation of the camera and also geometry environment. This is because as soon as the camera moved, the registration process will no longer work.

Some research has also been done in non-real time AR system. For example in [29], [30] they demonstrated that occlusion can be resolved without depending on a 3D reconstruction of the scene. This is done by using a contour-based approach to label each contour as being in-front or behind the inserted virtual object. The advantage of this system is that it does not require 3D. Thus, the developed algorithm makes it quick and easy to implement. However, this approach can give unsatisfactory results (because not easy to be tracked) when it comes to the highly textured environment. So, it is suggested to include 3D reconstruction step in order to resolve the occlusion.

[35] in his study also used contour-based approach but in real time stereo matching to acquire an accurate depth image of the boundary real objects. The purpose of this study is to resolve the problem of occlusion for the case when user's hand is occluded by virtual objects in a tabletop AR system. The result shows that the problem of occlusion between virtual and real objects has been resolved. However there are still some

weaknesses in the process of stereo matching which is not perfect when it comes to specific cases.

Compared with previous studies, [16] introduced a new occlusion detection algorithm by judging the geometry relation between projection of virtual points and projection of real points according to the theory of stereoscopic geometry instead of by deepness calculation. An optimization algorithm on triangle mesh occlusion detection is presented for the case where occlusion detection status ~~is~~ failed. A precise epipolar constraint solving method is also included in this system to construct a fast, accurate and robust AR occlusion detection algorithm.

IV. DISCUSSION

Based on an above reviews, a few aspects of occlusion in AR environment can be formulated. Starting from occlusion issues which arised from the use of video-based AR display system which could have a negative impact on user, followed by the two methods suggested: model-based approach or based on depth. Finally, correction of occlusion on AR system is expected to bring a positive impact to the user (see Figure 4).

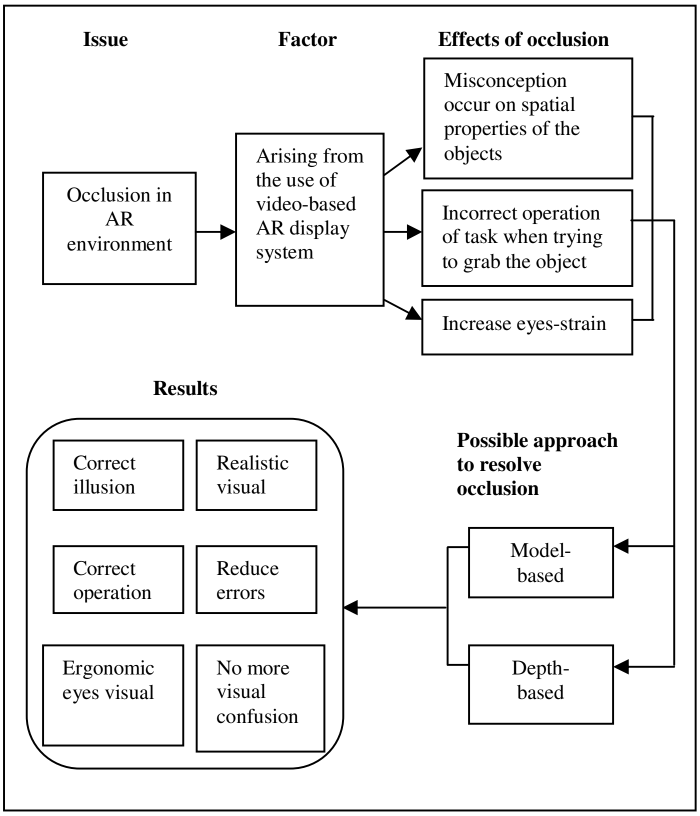

Figure 4: Research structure on AR occlusion

Table I summarised the dependency factors and characteristics that influence the selection of approach for occlusion handling in AR system. Occlusion handling method selection depends on factors such as a location of the real environment taken (i.e either indoor or outdoor scene), the selection of AR display system (i.e either video-based, optical-based or projector-based technology), and a number/type of camera(s) used (i.e either single camera, stereo camera or more than two cameras).

TABLE I. DEPENDENCE FACTORS FOR OCCLUSION HANDLING

Factors	Characteristics	Descriptions	Reasons
Real Environment Location	Indoor	1. Depending on 3D model object availability. Virtual 3D model objects can be obtained either from :- i) existing CAD model; ii) re-model it ;or iii) 3D reconstruction. 2. Involve shorter distance. 3. Mostly used marker-based tracking.	1. Indoor - is considered as a prepared environment Eg.a camera viewpoint & background can be static and does not involve a complex environment. 2. Indoor space is smaller, thus the tracking is easier. 3. Sometimes require additional tools for 3D reconstruction, tracking and registration.
	Outdoor	1.Based on nature of the objects. Depending on physical object characteristics & appearance. 2. May involves a short or long distances that are located from the observer of the scene. If involve a short distance and simple scene, marker card maybe used. Else, a markerless tracking technique by using computer vision and image processing knowledge is required.	1. Usually in the form of unprepared scene. Eg. Camera viewpoint & background can be either static or dynamic. May involve a cluttered scene and larger space, thus occlusion handling and tracking process become harder. 2. Often require additional tools such as GPS, trackers or sensor to track objects.
Display System Technology	Video-based	1. Opaque display features. 2. Virtual objects are always between the observer and the real display scene.	1.Virtual objects always occlude the real object. 2.Most common type of AR display used by many researchers
	Optical-based	1. Semi-transparent display features. 2. The virtual object appear overlapped by a real object. Thus it is difficult to create the correct occlusion effect.	1.The incorrect occlusion caused by the virtual image reflected by semi-transparent mirrors. 2.Used by several researchers only.
	Projector-based	1. Opaque display features. 2. Real object is always between the observer's eyes and the display surface.	1. Real object always occlude a virtual object. But the virtual object cannot occlude real object since virtual graphic is shown on the screens background while all the real object is located between the observer and the virtual background.

Factors	Characteristics	Descriptions	Reasons
Number/Type of Caamera(s) Used	Mono-cular camera	1. Consist of using only one camera. 2. Mainly requires a 3D model of real objects beforehand. However a single camera depth map objects can also be obtained based on images from two different angles (just like a stereo camera)	Usually a model-based approach is used to handle incorrect occlusion.
	Stereo camera/ Depth camera	1. Consist of using 2 cameras separately or have been integrated into a single device such as binocular stereo HMD or Microsoft Kinect (also known as a depth camera).	1.These cameras can generate a depth map of the real object. Thus it can determine either an object is forward / backward based on the depth image. 2. Normally a depth-based approach is used to handle incorrect occlusion.
	Multi-ocular camera	1. Consist of using more than 2 cameras. 2. The purposes are to eliminate some difficulties in binocular stereo by adding the third camera. Eg. A trinocular stereo with linearly located three cameras can reduce stereo matching errors and also makes it easy to detect occlusion [38].	1. Depth-based approach is used to handle occlusion. 2. Knowledge of image processing is required to resolve this problem.

A comparison between a model-based and depth-based approach in terms of its advantages and disadvantages are further discussed in Table II.

TABLE II. A COMPARISON OF MODEL-BASED VS DEPTH-BASED APPROACH

Approach	Advantage(s)	Disadvantage(s)
Model-based Approach	1. Requires 3D model of real object beforehand. May obtained via develop a new one, use an existing model or 3D reconstruction 2. Usually monocular camera is used. 3. Suitable for simple and static scene such as indoor environment.	1. Difficult for complex environment i.e cluttered scenes (unprepared environment) 2. By using 3D reconstruction technique need accuracy of the reconstructed object.
Depth-based Approach	1. Does not require 3D model. Only need to generate depth images of real object. 2. Cater for both static or dynamic scene and suitable for simple to complex environment.	1. Require stereo camera or multiple or depth camera to generate depth maps. Involve additional hardware cost. 2. Require accurate depth images to be tracked. Else may give unsatisfactory result. 3. The main problem in binocular stereo is to find correspondences in stereo pair [38]. 4. Depth map is dependent on the user's position, head orientation, and location of real objects. Any changes on these factors, the depth map may becomes invalid [5].

V. CONCLUSION AND FUTURE WORK

Occlusion in AR becomes one of the most important elements to improve the visualization rendering in AR scene. It enhances the presence of the object realistically. This paper focuses on overview of occlusion approach in AR system. Various methods were explored by several researchers in order to resolves the problem of occlusion. However, approaches discussed above can solve only part of occlusion problem in most cases. Until now the seamless integration between real and virtual objects especially occlusion is still a critical topic among researchers in AR applications.

Since our AR assembly setup is a simple indoor environment scene with an available 3D model of Arrick components from previous studies [39], the future work will include a model-based approach with marker-based tracking to solve the problem of occlusion in Arrick robot assembly application.

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