Development of a Handheld Mobile Augmented Reality Application ARC-3DM: A Prototype Tool to Determine 3D Modelling Competency

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Abstract

The Augmented Reality Courseware for 3D Modelling or better known as ARC-3DM was a prototype handheld application that utilized the mobile-augmented reality (MAR) technology and marker-based augmented reality (AR) technology integrated with multimedia and 3D elements. The AR system in ARC-3DM can be accessed using buttons by using haptic touchscreen technology. The ARC-3DM was designed and developed based on ADDIE instructions. The greatest contribution of ARC-3DM which utilized the marker-based AR technology was its capability to determine the users' 3D modelling competency as well as an aid for the task of 3D modelling. The progress of 3D modelling was pre-evaluated in each step of marker to determine the 3D modelling competency based on certain parameter before it can proceed to next marker until completion. With the integration of multimedia and 3D elements, learning experience could be optimized by reducing cognitive load and as well as improving the spatial visualization skill. The digitization of ARC-3DM allows the utilization of data without suffering from the real consequences of human errors. Moreover, the authentication process can be done by entering a password to prevent outsiders from accessing the application. This application has been tested for its functionality by students from Community College undertaking 3D animation course in Malaysia by measuring the significant values of correlation and regression using the straight line formula $y = mx + c$. However, for future improvement and planning, other parameters or features can be added into ARC-3DM such as an action history that can display the actions done by user such as mistakes so that the user can improve and develop more on the knowledge in order to heighten the skills.

Keywords: ARC-3DM, augmented reality, 3D modelling competency

1.0 Introduction

3D animation is produce in three phases, which are the pre-production, production and post-production. Technically, 3D artist will be using the 3D animation authoring tool and other related software to produce the 3D animation project. The focus in this paper is on the second phase, which is the production. The topic selected for the phase of production will be the 3D modelling. It is important to strengthen the 3D modelling skill at satisfactory level of competency before proceeding to the next phases in 3D animation project. According to George, Liacouras, Rybicki & Mitsouras (2017), in animation industry, the visual quality of 3D model becomes one of the main points of attention and there is more and more demand for 3D model with higher accuracy.

2.0 Problem statement

The end product of a 3D project is completed in the third or final phase which is the post-production. Therefore, in order to solve the problem of an end product of a 3D project that fail to meet a certain satisfactory level, it is important to make sure the issue of satisfactory level is solve and fulfil in earlier phase which is the production phase. The production phase was chosen because it is a phase where the development of raw mesh 3D product was actually executed and the output product in this phase will hold a major power in appealing to the audience or target market. The pre-production phase was not chosen because it is the first phase that does not involve with 3D execution and only involved with the creation of idea such as creation of story plot, graphic creation of character or props and creation of storyboard. A method or tool that can aid in enhancing the users' 3D modelling skills and monitor the users' 3D modelling competency is really important in order for the user to improve the 3D project so that the quality of the creative content could meet the demand of the industry. In this paper, the design and development of mobile augmented reality application ARC-3DM is proposed and presented.

The Augmented Reality Courseware for 3D Modelling or better known as ARC-3DM was a prototype handheld application that utilized the mobile-augmented reality (MAR) technology and marker-based augmented reality (AR) technology integrated with multimedia and 3D elements. MAR technology combines real and virtual object into the real world, registers and aligns the real and virtual objects with each other and it runs and display the augmented view on a mobile device and is interactive in real time (Kock, 2010; Karimi & Hammad, 2004; Renevier & Nigay, 2001; Azuma et al., 2001; Azuma, 1997).

The greatest contribution of ARC-3DM which utilized the marker-based AR technology was its capability to determine the users' 3D modelling competency as well as a learning aid for the task of 3D modelling. The marker-based augmented reality technology in ARC-3DM enable the system to pre-evaluate and identify the quality of the user's 3D model in progress based on a certain parameter of marker to determine the user's level of competency in 3D modelling. With the data being stored in online clouds, ARC-3DM runs entirely on smartphone and can be accessed using buttons through haptic touchscreen technology.

The ARC-3DM was integrated with multimedia and 3D elements. Separated segments of multimedia content optimized learning experience by reducing extraneous cognitive load in content data which could lead to confusion (Mayer & Chandler, 2001; Sweller, 1988). The integration of ARC-3DM with 3D model in interactively three dimensional view could promote the improvement of mental rotation skill (MRS) which is the ability to mentally transform 3D objects and virtual images by rotating it in the space (in mind). According to Ernst, Lane & Clark (2015), by improving MRS, it will improve the spatial visualization skill thus avoid overloaded in cognitive load of memory. Engineering, architecture, and most scientific and technical jobs such as 3D modelling require people to have good spatial thinking skills (Gutiérrez, Contero & Alcañiz, 2015).

3.0 Objectives

In order to test the functionality of ARC-3DM, simulation test was conducted by participant of students in Community College from 3D animation course. The performance comparisons between simulated tests on measured variables was analyzed by measuring the significant values of correlation and regression using the straight line formula $y = mx + c$ and the result are presented and discussed. The objectives of this study are:

a. To design and develop the ARC-3DM.
b. To evaluate and discuss the relationship between the control parameters (Polygon 3D model and Nurbs 3D model) and the output response of augmented marker.
c. To evaluate and discuss the prediction power between the control parameters (Polygon 3D model and Nurbs 3D model) for the output response of augmented marker.

4.0 Methodology

The ARC-3DM is designed and developed using the instructions in ADDIE model, which involved of section 2.1 Phase I: background analysis, section 2.2 Phase II: data selection & learning the content, section 2.3 Phase III: structure the lesson and production of content, section 2.4 Phase IV: digitization of content, section 2.5 Phase V: multimedia design, section 2.6 Phase VI: development and implementation in ARC-3DM system, section 2.7 Phase VII: testing, consultation, and modification and section 2.8 Phase VIII: completion of ARC-3DM.

4.1 Phase I: background analysis

The background analysis for the ARC-3DM was conducted by literature review from animation reference books and from related research on design and development, technologies on augmented reality, multimedia, learning theories and instructional model. The background analysis obtained includes aspects such as target audience, course content, learning style, learning objectives, and learning outcome.

4.2 Phase II: data selection & learning the content

In this phase, materials that are relevant to the subject matter are selected from reference books, original source materials and from people knowledgeable in the area. The main topic selected for the development of ARC-3DM is 3D modelling which is the production phase in 3D Animation Process. It is also important for designer to learn the subject matter or the contents to become thoroughly familiar to ensure effective development that includes instructions which challenges the users in creative ways as well as promotes the learning effect interactively. Shallow understanding can only produce a shallow lesson. Therefore, it is important have complete understanding on the subject matter to make sure the content to be functional and fulfil the purpose of its development.

4.3 Phase III: structure the lesson and production of content

A structure is a series of diagrams describing flow of operations that best depicted as a visual representation of decisions and events. It should include information about when the window will draw or animate pictures. It shows what the expectation from the operations. Figure 1 illustrates the flow operations of ARC-3DM.

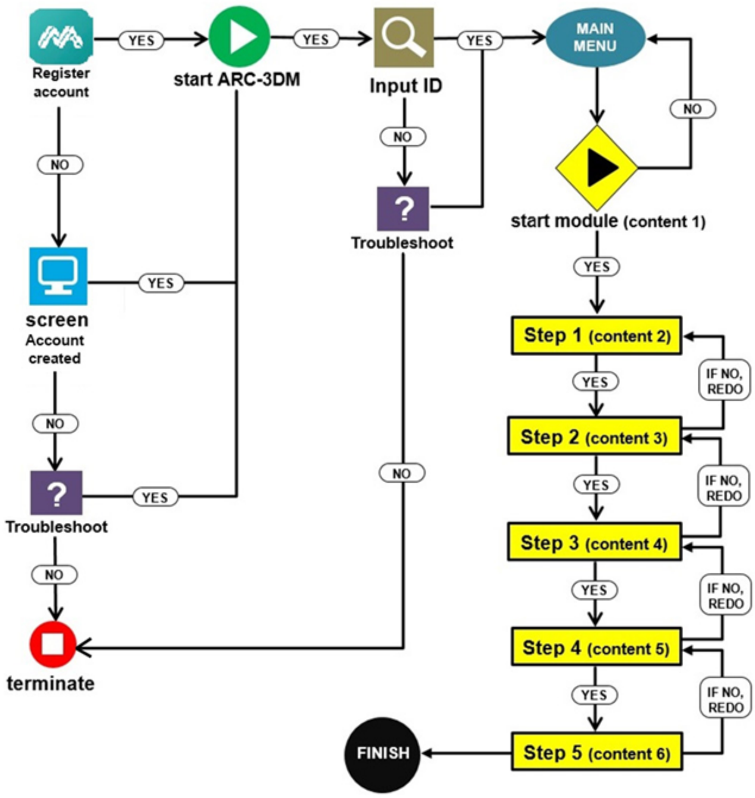

Figure 1: ARC-3DM operation flowchart

4.4 Phase IV: digitization of content

The contents, which divided into two types, were the static and dynamic content. For static content, the items were graphic illustrations and text. For dynamic content, the items were the 3D models, animated video and audio. The graphic illustration, which was the static content, was created using graphic design authoring tool, Adobe Illustrator and Adobe Photoshop. Color, typography and composition were used to enhance and to attract attention for the users. Audio are composited into and edited using audio authoring tool called Sound Forge to enhance users experience thus increase understanding on the topics being learn. Videos were combined with narrated audios and edited using audio video authoring tool which was Adobe Premiere in a way that can convey meaning and fulfil attractive learning process. 3D element which were the 3D models are created using 3D authoring tool called Autodesk MAYA in order to contribute as a method to enhance spatial skill in visualizing the 3D object to be modelled in three-dimensional view.

4.5 Phase V: multimedia design

The application courseware design is essential to the effective use of multimedia and educational technology so that the interaction between the meaning and media can be conducted in the learning and task execution process. In this study, a handheld AR system which refer to the ARC-3DM was developed and integrated with combination of static and dynamic multimedia content and 3D element including image, text, video, 3D model and audio on a real environment. The ARC-3DM AR content was inputted by filling the handheld AR system with separated multimedia content module for 3D modelling task.

In this ARC-3DM, the content was implemented interactively so that the user can control their action at their own pace and deliberately practice as well as for their self-evaluation with the application to determine current level of competency and also re-exercise again to increase competency level. According to Moreno & Mayer (2000), the pace of presentation is controlled by the learner, rather than by the learner. This provide the opportunity to the user to be adventurous and be able to take risks in order to develop more and heighten their skills (Ng & Shaziti, 2004). The content of the AR application ARC-3DM was laid out with simplicity and consistency.

In Figure 1 ARC-3DM Flowchart, the content is divided into 6 sections: Start Module, Step 1, Step 2, Step 3, Step 4 and Step 5. The design for the ARC-3DM has to consider two important elements which are the Interface design and content presentation. As shown in Figure 2 ARC-3DM main menu, for the Interface design, it is based on eyes movement which begin with the MAIN MENU which have 6 items which is displayed beginning from left to right screen in the form of zig-zag pattern in orderly. This serve as a guide to the user on how to use the courseware effectively

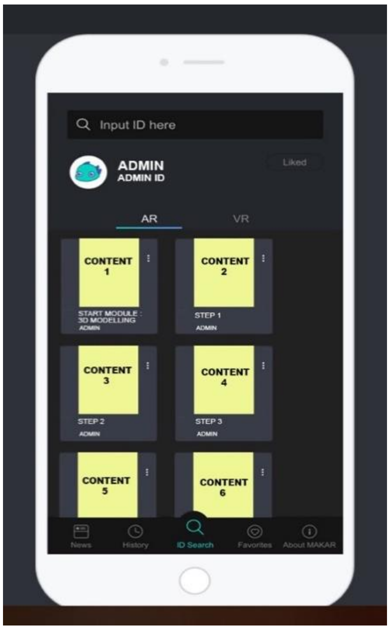

Figure 2: ARC-3DM main menu

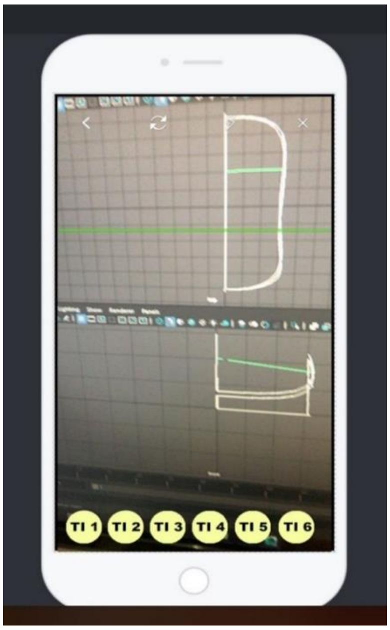

Figure 3: ARC-3DM target images (TI)

Referring to Figure 3 ARC-3DM target images (TI), the interface design includes number of Target images (TI) to expect the navigation steps for image recognition for augmentation. This were the steps where developer augmented the real environment. The target images were the 3D models modelled by the user, which projected actively on the viewport of Autodesk MAYA. The augmented phase would only happen when the modelled 3D object done by the user match or meet a certain parameter quality of 3D modelling stored in the marker of the AR system in ARC-3DM. Another interaction to consider was the interaction between the animated graphics with the narrated voice over. By explaining through voice over, user could try to imagine the visual output. The animated graphics, which congruent with the narrated voice over helps to understand the topics much easier (Moreno & Mayer, 1999; Moreno, Mayer, Spires & Lester, 2001). For the content presentation, the information relevant to the topic were collected and drafted. The experts in 3D modelling evaluated the collected information. Once the information is reconfirmed for its accuracy, the development process began.

4.6 Phase VI: development and implementation in ARC-3DM system

Once all the previous phases carried out, the ARC-3DM could be developed. The contents for the topic are presented interactively to increase user enthusiasm, focus, and enjoyment. The user also has better control of the application by stopping and forwarding at their own pace. The main authoring application used for the AR development process was MAKAR for development, assembling and navigation using AR SDK aided by other authoring tools such as Autodesk MAYA 3D for 3D model creation, Sound Forge for audio editing, Adobe Photoshop and Illustrator for graphic design creation and Adobe Premiere Pro for video audio editing.

There were four main components in ARC-3DM: (1) a camera to capture a target information, (2) marker which is the target information, (3) mobile phones to store and process information when the captured image is the target information (marker), and (4) digital content will be displayed on the screen when the camera is able to track the marker. For this study, the type of AR technology being developed was a handheld mobile augmented reality system application which emphasize on the use of smartphone. Figure 4 illustrates the package diagram of the prototype ARC-3DM which was developed. The main part of the system is the Controller, which has access to 3D modelling task module contents, sensors (cameras), and user inputs. The Controller receives the marker ID and camera view matrix from the Tracker and uses this information to specify the behaviour of the on-screen display. The AR system runs entirely on smartphone and the operating system's platforms that was used were Android and Macintosh. After identifying the marker, the system loads the corresponding text, video and image in the Content Manager. It can be accessed through buttons by using Haptic Touchscreen technology.

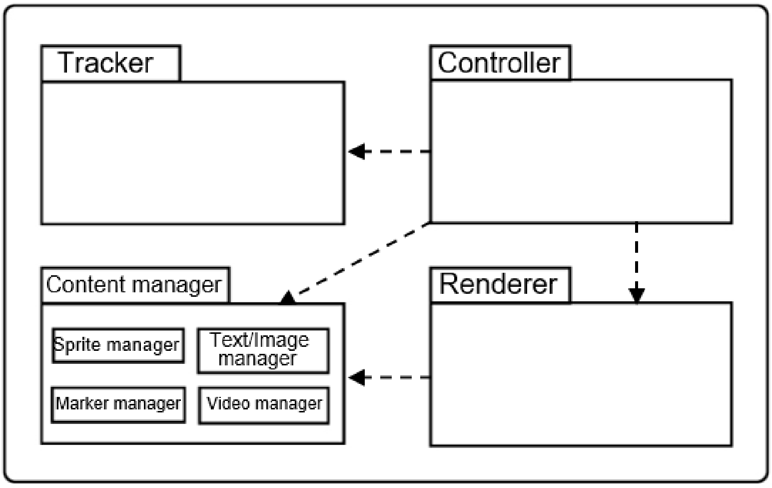

Figure 4: ARC-3DM handheld augmented reality system

4.7 Phase VII: testing, consultation, and modification

The development of ARC-3DM was based on User-Centered Design (UCD). Therefore, it is crucial to make sure that there will be no errors left by testing it from the beginning of the development to its final phase. Modifications have to be made to the ARC-3DM after checking, testing and consultation to ensure its usability and functionality of the application courseware.

4.8 Phase VIII: completion of ARC-3DM

This ARC-3DM project was completed once all the contents, navigation and functionality have been tested and accepted by the developer. For this project, the topics are all presented in orderly and the functionality was tested in test simulations after a series of trial and error and the statistic result was evaluated.

5.0 Results

Figure 5 illustrates the completion of ARC-3DM and the steps of operation using the ARC-3DM for the task of 3D modelling. The first step using ARC-3DM begins with authentication process by entering a password to prevent other outsiders from accessing the application. After login successful, scan a specific first QR code to start the 3D modelling task module. Referring to Figure 6, ARC-3DM implemented two types of marker which were two QR codes and the 3D models in progress modelled by user which displayed in the 3D authoring tool of Autodesk MAYA viewport.

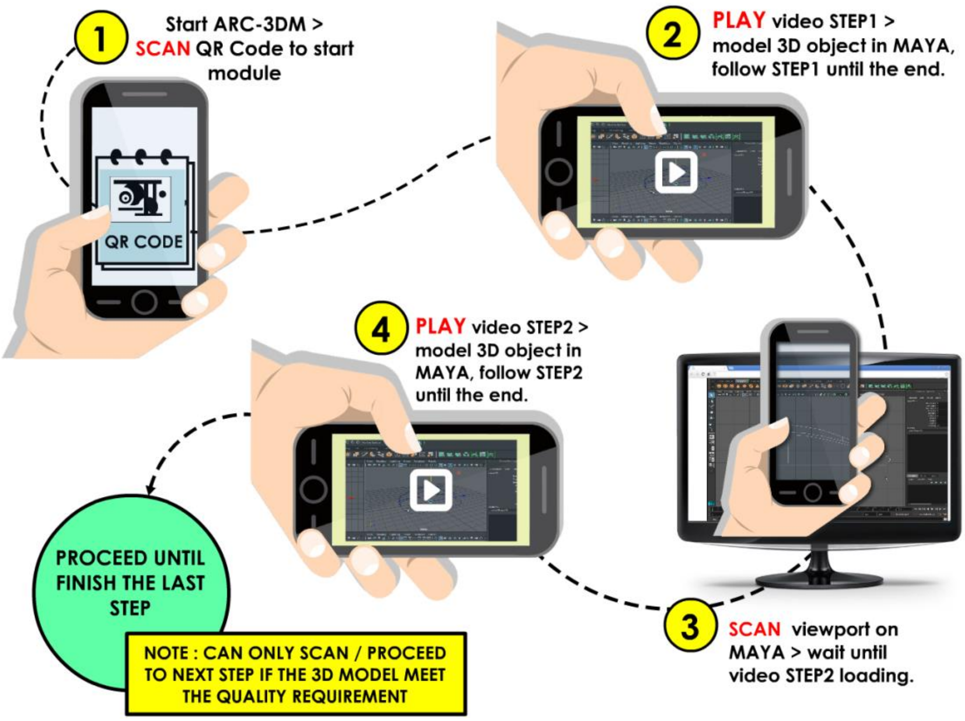

Figure 5: ARC-3DM steps of operation

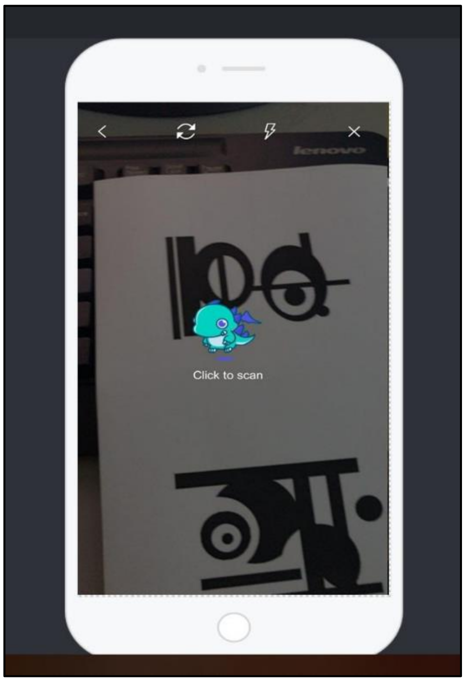

Figure 6: ARC-3DM scanning phase (Two QR codes)

5.1 ARC-3DM output response of augmented marker – QR codes

Referring to Figure 7 and Figure 8, for the QR codes, ARC-3DM utilized two QR codes. The first QR code was for augmenting the starting point of 3D modelling task module while the second QR code was for augmenting the interactively three dimensional view of 3D model reference for the 3D modelling task module. This integration of 3D model reference in interactively three dimensional view could promote the improvement of mental rotation skill (MRS) which is the ability to mentally transform 3D objects and virtual images by rotating it in the space (in mind). By improving MRS, it will improve the spatial visualization skill thus avoid overloaded in cognitive load of memory (Ernst, Lane and Clark, 2015). Technical jobs such as 3D modelling require people to have good spatial visualization skills in order to visualized the 3D model without missing any details efficiently in three dimensional view (Gutiérrez, Contero & Alcañiz, 2015).

The 3D model reference served as a guide and act as a catalyst in helping the user to visualized the full appearance of the 3D model that need to be modelled for the 3D modelling task. The QR code and the markers for any 3D modelling task module will be vary and can be customized according to the type of 3D modelling task to be conducted. The QR codes was printed on a paper and the user only need to use a mobile phone with platform Android or Macintosh and with the ARC-3DM application installed to conduct the task.

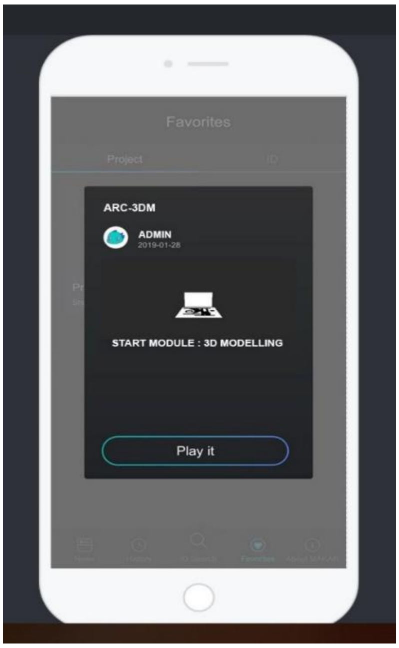

Figure 7: ARC-3DM augmented phase of first QR code starting 3D modelling task module

Figure 8: ARC-3DM augmented phase of second QR code displaying interactively 3D model reference in three dimensional view

5.2 ARC-3DM output response of augmented marker – Polygon and Nurbs 3D model

At this stage, the augmented marker used were Nurbs and Polygon 3D model which being modelled by the user. This stage was the time that the functionality of the ARC-3DM was tested. At the same time, this stage also the period when the user's competency in 3D modelling was determine. Figure 9 illustrates the scanning phase of user's 3D model in progress in Autodesk MAYA viewport and the output response augmented of an interactive multimedia content of video with narration and text.

The user will be engaged with a 3D modelling task module step by step accordingly using five markers for augmentation progressing of completion from first marker with 20% completion, following with second marker with 40% completion, following with third marker with 60% completion, following with fourth marker with 80% completion and finally the last marker of the fifth marker with 100% completion. The augmented phase would only happen when the modelled 3D object done by the user manage to match or meet a certain parameter quality of 3D modelling marker stored in the AR system of ARC-3DM. Therefore, this feature was used to determine the user's competency in 3D modelling. For example, if the user's 3D model successfully augmented the third marker and cannot augmented for the next marker which is the fourth marker, then the user's capability is only at 60% of completion.

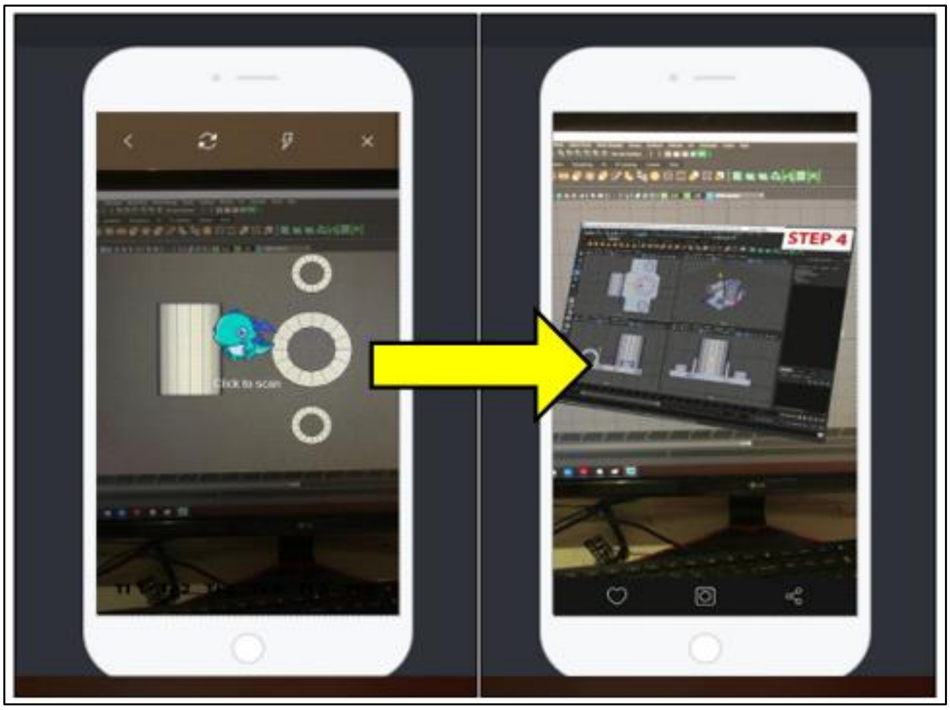

Figure 9: ARC-3DM scanning phase of user's 3D model in progress in Autodesk MAYA viewport and the output response was an augmented phase of an interactive multimedia content of video with narration and text

6.0 Statistical analysis and discussion

In order to test the functionality of ARC-3DM, simulation test of 3D modelling was conducted by 11 sample of participants of students in Community College from 3D animation course. The test aims to investigate the relationship and prediction power between the output response of augmented markers in ARC-3DM and the target recognitions of the 3D model of Polygon and Nurbs shown in the Autodesk MAYA viewport. The performance comparisons between simulated tests on measured variables was analyzed by measuring the significant values of Pearson correlation and regression using the straight line formula y = mx + c to evaluate the prediction power of the variables being tested.

6.1 ARC-3DM simulated test result – statistical analysis on correlation

Simulation test was conducted to investigate the ARC-3DM functionality and performance by investigating the relationship between measured variables of Polygon 3D model, Nurbs 3D model and Output response of augmented marker. The statistical method used for analyzing the statistical data was Correlation and the hypotheses being tested in this test were:

$H_{01.1}$: There will be no statistically significant correlation between Polygon 3D model and Output response of augmented marker.

$H_{01.2}$: There will be no statistically significant correlation between Nurbs 3D model and Output response of augmented marker.

Table 1: Correlation table

Correlation				
		Output response of augmented marker	Polygon 3D model	Nurbs 3D model
Pearson Correlation	Output response of augmented marker	1.000	.979	.971
	Polygon 3D model	.979	1.000	.946
	Nurbs 3D model	.971	.946	1.000
Sig. (1-tailed)	Output response of augmented marker	.	.000	.000
	Polygon 3D model	.000	.	.000
	Nurbs 3D model	.000	.000	.
N	Output response of augmented marker	11	11	11
	Polygon 3D model	11	11	11
	Nurbs 3D model	11	11	11

From the result in Table 1: Correlations table, we could see that there is a strong positive correlation between Polygon 3D model and Output response of augmented marker which indicated by, Pearson r= +0.98 with significant level of p=0.00, p<0.05 which therefore rejected the $H_{01.1}$ null hypothesis. This showed enough evidence that there is statistically significant correlation between Polygon 3D model and Output response of augmented marker. Therefore, there is indeed exist a positive relationship between Polygon 3D model and Output response of augmented marker.

From the result in the Correlations table, we could see that there is a strong positive correlation between Nurbs 3D model and Output response of augmented marker which indicated by, Pearson r= +0.97 with significant level of p=0.00, p<0.05 which therefore rejected the $H_{01.2}$ null hypothesis. This showed enough evidence that there is statistically significant correlation between Nurbs 3D model and Output response of augmented marker. Therefore, there is indeed exist a positive relationship between Nurbs 3D model and Output response of augmented marker.

From the result, it shows that the marker in ARC-3DM and the target recognition of Polygon and Nurbs 3D model in Autodesk MAYA viewport are capable of reacting positively between them to augment the outputs. This result is consistent with the findings by Kurpytė & Navakauskas (2014) and Schlaug (2011) that examine the factors in target recognition that contributes to the successfulness of a marker recognition algorithm in the domain of 3D model. Kurpytė & Navakauskas (2014) in their study, stated that black square and circle marker with a thick border such as a black and white QR Codes are the most accurate for marker-based systems because (1) its form can be easily found even using different methods or algorithms, (2) the colour contrast of black is easily noticed and differentiate even with different cameras and (3) the border type is more robust in most of the situations which can be applied. A study by Schlaug (2011) also proven that through the analysis on target image of a feature-based recognition for restoring 3D information using a single image. In a feature-based recognition, the lines and edges from the image are extracted and only using these to compute the algorithm instruction to augment the outputs. This also has the advantage of being more stable in different light conditions. As long as the three points that span a plane in the 3D model to recognise can be identified and their corresponding positions in the image, the output response will be augmented.

6.2 ARC-3DM simulated test result – statistical analysis on regression

Simulation test was conducted to investigate the ARC-3DM functionality and performance by investigating the prediction power between measured variables of Polygon 3D model, Nurbs 3D model and Output response of augmented marker. The statistical method used to analyze the data was Regression and the hypotheses being tested in this test were:

$H_{02.1}$: Polygon 3D model is not a significant predictor for Output response of augmented marker.

$H_{02.2}$: Nurbs 3D model is not a significant predictor for Output response of augmented marker.

Table 2: Coefficient table

Coefficients[a]								
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	58.706	6.452		9.098	.000		
	Polygon 3D model	1.463	.102	.979	14.300	.000	1.000	1.000
2	(Constant)	30.994	11.944		2.595	.032		
	Polygon 3D model	.861	.248	.576	3.470	.008	.105	9.525
	Nurbs 3D model	.335	.131	.425	2.563	.034	.105	9.525

a. Dependent variable: Output response for augmented marker

Looking at the result in Table 2: Coefficients table, found that the significant p value for variable Polygon 3D model was, p=0.01, p<0.05, therefore the null hypothesis $H_{0\ 2.1}$ was rejected. Therefore, Polygon 3D model is a significant predictor for Output response for augmented marker.

The result found that the significant p value for Nurbs 3D model was, p=0.03, p<0.05, therefore the null hypothesis $H_{0\ 2.2}$ was rejected. Thus, this showed enough evidence that Nurbs 3D model is a significant predictor for Output response for augmented marker.

Table 3: Summary table

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.979[a]	.953	.953	2.94931
2	.988[b]	.977	.971	2.31821

a. Predictors: (Constant), Polygon 3D model
b. Predictors: (Constant), Polygon 3D model, Nurbs 3D model

The result also stated that the R square for both variables which are, $R^2 = +0.977$ which indicated that 97.7% of variance in variable Output response for augmented marker could be predicted by the two independent variables which are Polygon 3D model and Nurbs 3D model.

Regression equation (testing)
with c=a=constant , with m=b=slope , with x=X= independent variable

$$
\begin{aligned}
y &= mx + c \\
&= c + mx \\
&= a + bX
\end{aligned}
$$

For example 1, Output response for augmented marker? If Polygon 3D model =60
y = 30.994 + (0.861(60))
= 30.994 + 51.66
= 82.654
(Therefore, if Polygon 3D model is 60, the Output response for augmented marker will be predicted to be about 82.654)

For example 2, Output response for augmented marker? If Nurbs 3D model =80
y = 30.994 + (0.335(80))
= 30.994 + 26.8
= 57.794
(Therefore, if Nurbs 3D model is 80, the Output response for augmented marker will be predicted to be about 57.794)

7.0 Conclusion

From the inferential analysis result have found that there exists positive relationship between independent variables tested which are the Polygon 3D model (Pearson r= +0.98), Nurbs 3D model (Pearson r= +0.97) with the dependent variable Output response for augmented marker. The investigation on performance comparisons between simulated tests on measured variables to evaluate prediction power using regression equation of y = mx + c have found that the variable Polygon 3D model and variable Nurbs 3D model are significant predictors for the variable Output response for augmented marker with a strong prediction power of 97.7% with the value of R^2 = +0.977 which indicated that 97.7% of variance in Output response for augmented marker could be predicted by the two independent variables which are the Polygon 3D model and Nurbs 3D model. This study also consistent with the study by Kurpytė & Navakauskas (2014) and Schlaug (2011) that mentioned the implementation of black and white QR Codes and images of a feature-based recognition as the object recognition or the target image contribute towards the successfulness of a marker recognition that significantly boost the prediction power of the predictors variable Polygon 3D model and variable Nurbs 3D model for the variable Output response for augmented marker. Statistical results from this study has proven that the ARC-3DM is functioning well through the positive relationship between independent variables of Polygon 3D model and Nurb 3D model with the dependent variable Output response for augmented marker. In addition, the findings that the variable Polygon 3D model and variable Nurbs 3D model are significant predictors for the variable Output response for augmented marker in this study also has shown that the ARC-3DM is capable to be used as a tool to determine competency for the task of 3D modelling as well as to be used as an aid in learning and executing the task. Measuring the functionality of ARC-3DM is very important since the visual quality of 3D model with higher accuracy has become one of the main points of attention in the animation industry (George et al., 2017).

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