Gait Analysis Data Visualisation in Virtual Environment

(GADV/VE)

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***Abstract*—A prototype virtual reality application has been developed as a diagnostic tool to aid visualisation of gait analysis and improve accessibility for health professionals who lack the technical experience to operate motion capture systems. The proposed system will take motion capture data stored in the Coordinated 3 Dimensional (C3D) file format and present the data as a visualisation in a three dimensional (3D) virtual environment. This article is presenting the design and development considerations, the evaluation results based on usability traits of this system and the user acceptance of the technology as a viable diagnostic tool.**

A virtual reality application was developed for the purposes of visualising motion captured data for gait analysis in a virtual environment. Twenty users with relevant experience in the field of gait analysis participated in user trials to gauge user reaction and acceptance of the proposed system. An adapted version of the Technology Acceptance Model (TAM) framework was used to analyse results. All trials were conducted in an in-house virtual reality and simulation laboratory. The intention of health professionals to use the system was explored based on the TAM, with added constructs that concern virtual environments: Technical aspect (TA), Orientation (Orient.), Physical and emotional (PhE), and Availability of hardware in-house (AHWH). Based on the TAM and extended factors the findings suggest that the system was perceived as useful and health professionals' intentions to use the GADV/VE system were strongly affected by technical aspects and availability of hardware in-house and moderately affected by orientation and physical and emotional side effects.

Results from the output of the TAM framework show that the virtual reality application for gait analysis would be a valuable tool in the diagnostic stage of gait analysis and was positively received by health professionals in the relevant field.

Keywords—Gait Analysis; Virtual Reality; C3D; Usability; HCI; Musculoskeletal; TAM

I. INTRODUCTION

When studying human locomotion, motion capture becomes a valuable tool for medical practitioners with C3D being a file format adopted by many major motion capture companies. Using C3D for gait analysis often requires a skilled professional to process data and attach it to a 3D skeleton. The purpose of this work is concerned with the development of interactive visualisation software that assists health professionals in enhancing medical data visualisation by making data derived from motion capturing human locomotion in the C3D format more accessible. The proposed system aims to utilise a 3D representation of the motion capture data with specific gait analysis manipulation icons in an interactive virtual reality (VR) environment [1]. It is intended that the 3D mental mapping will enhance gait data visualisation and support the decision making process as presented in previous studies [2-5]. Furthermore, VR enhances interaction by allowing users the ability to explore structures from several viewpoints and has proven its efficacy when used for rehabilitation and tele-rehabilitation [6-9].

Factors affecting health professionals' acceptance of new technology (GADV/VE system) were examined prior to the system's development. Theory, such as the TAM [10], helps in understanding how end users form attitudes and use technologies in Virtual Environment (VE). In this work, an empirical investigation was performed on an extension of the TAM to explain the acceptance of a GADV/VE system.

TAM was applied to explain the acceptance of many information systems [11]. Whilst this research is not the first that applies TAM to VE context [12-14], it aims to contribute to the existing work on three novel fronts. Firstly, focus was given to the application of TAM framework for the specific field of gait analysis and the visualisation, specifically for skeletal elements of the leg in the VE. Secondly, new constructs were introduced to the model to cover aspects related to the virtual environments. Finally, the system evaluation/testing were conducted by users relevant to the field i.e. expert health professionals in the fields of musculoskeletal and neurological rehabilitation, and not random samples who may be less involved or aware of applications currently in practice.

Conceptually, perceived ease of use (PEoU) and usefulness (PU) were examined along with their impact on attitude toward usage (ATU) and behavioural intention toward using the system (BIU). The paper also introduces new constructs concerning virtual environments [15], including TA, Orientation, and PhE. Another construct was added specifically to measure the importance of an in-house Virtual Reality and Simulation (VRS) laboratory where the users' trials were based, denoted as AHWH. This work suggests that the aforementioned constructs influence ease of use, usefulness and intention toward using the system. Research questions concentrated on defining the views of health professionals towards GADV/VE based on constructs of PEoU, PU, ATU, BIU, AHWH, TA, Orientation, and PhE, elucidating the relationships between constructs and determining which construct(s) affect(s) the user intention to use GADV/VE.

II. SYSTEM DEVELOPMENT

A. Gait Analysis Data Visualisation Software

Accessibility may be an obstacle when attempting to visualise motion capture data. C3D files are created in binary format. This normally means specific software is required to interpret the data. Issues arise with software like this as it requires a health professional to be trained in the use of the software. This skilled user would then be required to manually map data capture markers to 3D geometry that has been created as an anatomical representation of whatever area is being analysed. This is necessary due to the flexibility of the C3D file format and its capability to store many different kinds of data. It is also necessary to have an understanding between the personnel responsible for acquiring the data using the motion capture equipment and personnel processing the data with the software due to the complexity of the format and the flexibility it allows. The target area, each motion capture marker is mapped to, needs to be known by the user involved with processing the data.

A purpose built application was created to parse the data into a usable format, and then display this data in a meaningful representation to the user. This software would allow any end user to view the data without needing additional specialised software for viewing. It would also eliminate the need for a trained professional to process the data before visualisation. However, it would impose a restriction on the personnel capturing the data, as the data would need to be structured appropriately at the motion capture stage.

For analysing human locomotion, physical measurements need to be extracted from the C3D file format in the form of 3D coordinates representing the positional information. The labels also need to be acquired when parsing the C3D file to create an understanding of what each marker represents. The naming of markers must conform to a predefined convention to allow the parsing and processing of the data to be automated.

Two types of markers are expected when processing the data: anatomy markers and movement markers. Anatomy markers denote where certain anatomical landmarks are situated. Movement markers determine the position and orientation of specific body parts for each frame of the locomotion captured.

Positional data for anatomy markers are only required from one frame that is used as a reference. The spatial relations of these markers to the movement markers for this one frame are calculated and the rest of the anatomy markers are disregarded. They are no longer needed as the position of specific anatomical landmarks can be deduced by retaining the spatial relationship with the movement markers established in the reference frame. The spatial relationship between these markers is illustrated in Fig. 1. Fig. 2 shows the movement markers on their own.

The reference frame selected was the frame occurring in the middle of the frame list. The reason for this is due to start and end frames being more prone to occlusion in the motion capturing process as these frame are more likely to occur at the outer ranges of the motion capture equipment, whereas a central frame is more likely to occur at the centre of the equipment's visibility.

With this data, and correctly named labels, the process of attaching these markers to geometry can be automated. In this case the geometry is the skeletal elements of the leg, from hip to foot.

The goal of this application was to increase the accessibility of viewing the gait data captured and represented in the C3D format. This is supported with the inclusion of a simple and intuitive user interface to allow simple manipulations of the data set visualisation.

The virtual environment is facilitated by presenting data to the user via a stereoscopic projector. The aim of presenting in this stereoscopic format was to increase spatial relation information during observation of the gait.

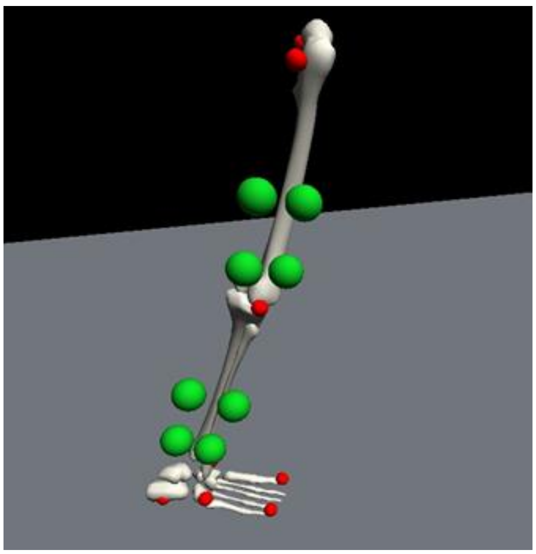

Fig. 1. Spatial relationship between anatomy markers, show as small red spheres, and movement markers shown as large green spheres

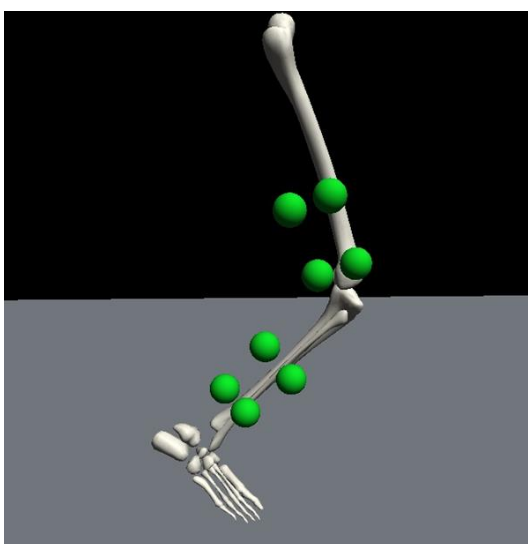

Fig. 2. Movement markers on their own. Bone positioning can be deduced from the relationship calculated between movement and anatomy markers in the reference frame

B. System Interface

This Section proposes the design for a novel user interface that provides a direct manipulation interface employed to navigate and interact in a 3D space. The use of off-the-shelf input devices minimised the cost dramatically and increased system availability and sustainability taking into consideration the design factors that enhance visualisation: structure, colour, and motion. The prototype VR interface was used to enhance visualisation and consequently improve therapy time allocation, as well as enable the communication between health professionals and patients. Processing motion capture data (C3D file) to be accessed in VE will utilise the VR-enhanced visualisation and improve medical data analysis. Furthermore, to make the processed C3D file more accessible it was designed to be viewed in the 3D web based system.

The goal of this application was to increase the accessibility of viewing the gait data captured and represented in the C3D format. This is supported with the inclusion of a simple and intuitive user interface to allow simple manipulations of the data set visualisation. These considerations led to the design of a user interface adjusted for 3D motion capture data by using well known off-the-shelf input devices that provide interaction in both desktop and semi immersive virtual environments (via 3D Television (TV), 3D laptop, or projection wall).

The design of the interface is demonstrated in Fig. 3. The specific design was chosen because of the following specifications:

- The tools bar on the bottom of the screen to leave a wide space for the leg movement, rotation, and zoom in/out.
- The tools provided to enhance interactivity with the model are:
  - Play button to start movement: the first tool provided is the play button to attract the viewer's attention to start moving the 3D model in the space.
  - Pause: if the viewer wanted to focus on specific view of the model.
  - Playback/forward: for more flexibility the user can playback the model to view specific movement rather than playing the model several times to get a specific view for the model.
  - Change movement speed (normal speed, slow, intermediate, and fast): it was important for the clinicians to control the speed of the moving model. This will give the viewer a chance to compare the patient's walk in different speeds.
  - Show/hide anatomy markers: the anatomy markers were used to parse the data and the viewer still has the chance to see the markers on the model.
  - Show/hide move markers: an additional tool to view move markers.
  - Rotate: for simplicity the rotation option is provided in the mouse (Right click). This tool was not added to the screen not to let the user focus on how to click the button each time to rotate the model.

- Zoom in/out: the zoom in/out was also provided in the mouse by scrolling.

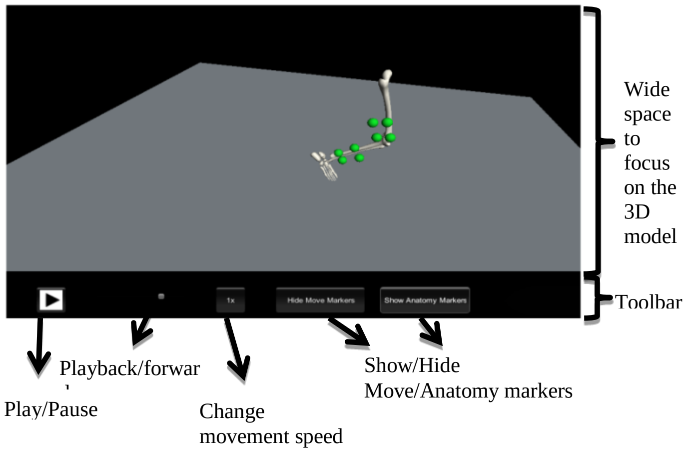

Fig. 3. The interface design for the parsed C3D data into a usable format

The virtual environment is facilitated by presenting data to the user via a stereoscopic projector. The aim of presenting in this stereoscopic format was to increase spatial relation information during observation of the gait. Semi immersive devices in VE (VRS lab) further enhance health professionals' interaction and understanding in addition to allowing collaboration to occur as shown in Figs. 4 & 5. Furthermore, VR is also delivered through laptop computers (advanced computer processor speed and graphics, and 3D glasses). This application offered to the viewer an option to run the system on a desktop computer and it can be accessed and interacted with electronically (via 3D web based medical record) which will be more useful (available anytime and anywhere) as diagnostic and visualising aids. But if the viewer did not have adequate facilities to view data in 3D, the viewer still has the option to utilise the visualisation of motion capture data on a flat computer screen.

The three possible usages of User Interface:

a. Remote manipulation of 3D data: wireless and gesture recognition mouse, 3D projector and head tracker, 3D glasses and head tracker, projection wall / 3D TV, motion capture-tracking gesture recognition.

b. Common mouse/keyboard on a stereoscopic display (3D Laptop and 3D glasses).

c. Common mouse/keyboard on a flat computer screen.

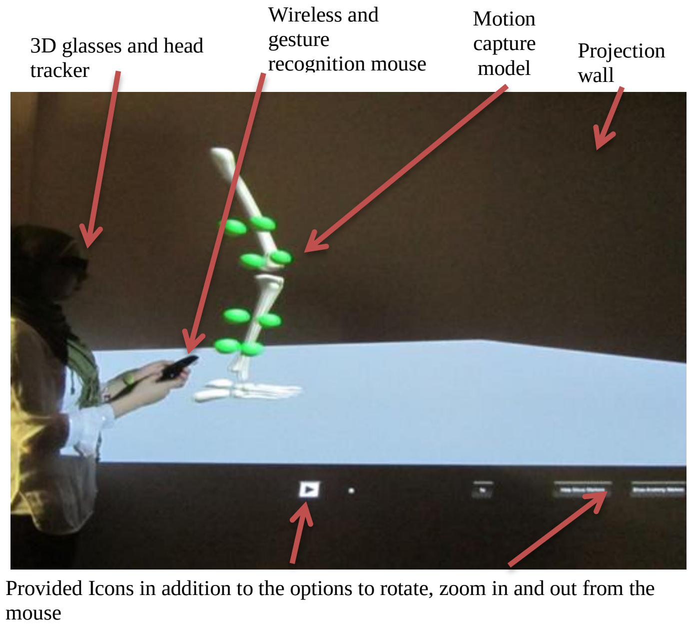

Fig. 4. Gait data visualisation in virtual environment / Semi immersive (VRS laboratory) using projection wall

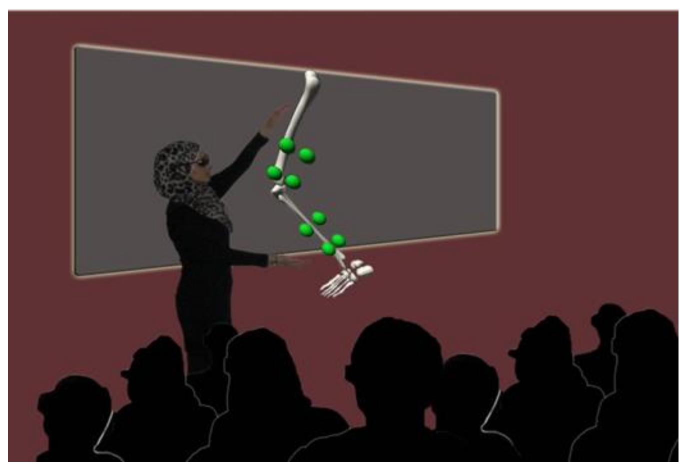

Fig. 5. Remote manipulation of 3D data in virtual reality and simulation laboratory

III. System Testing, Research Model and Hypotheses

After surveying a number of potential theoretical approaches for addressing the research hypotheses proposed in this work, the decision was made to evolve and examine an amended version of the extensively used TAM [10] as the principle for assessing user acceptance of GADV/VE technology. TAM has been widely used to examine users' intentions to opt for various types of information technologies as it is known as a robust predictive model [13, 16-17].

There are various variables that cause people to accept or reject technology. Among these variables, two determinants are suggested due to their importance: perceived usefulness and perceived ease of use [10]. The TAM suggests that a user's perception of perceived ease of use and perceived usefulness are considerable factors that influence the intention to use a computer application and effective usage. Furthermore, the TAM theorizes that information technology (IT) applications that are easy to use are also more likely to be perceived as useful [10].

In addition, previous research demonstrates that there are common construct variables that can be used to gauge technology adoption and acceptance, such as Behavioral Intention to Use (BIU), Attitude towards Technology (ATT), Subject Norms (SN), Performance Expectancy (PE), Socio-Demographical variables such as Gender, Experience, Age (GEN), and Anxiety (ANX) [18-23].

In this Section each construct and their underlying measurement items are presented in the completed survey which consists of two main sections, and a 7-point Likert scale (strongly disagree to strongly agree) has been used as a measurement scale (see Appendix). The questions were based on prior studies with modifications to fit the specific context of the GADV/VE and subsequently developed from TAM scales, adapted from [24, 22]. Based on TAM and extended TAM scales, the research model for this work examines 8 constructs shown in Table 1: Attitude Toward Usage (ATU), Perceived Usefulness (PU), Perceived Ease Of Use (PEoU), Physical and Emotional (PhE), Technical Aspects (TA), Orientation (Orient.), Availability of Hardware in-House (AHWH), and Behavioural Intention to Use (BTU).

TABLE I. TABLE CONSTRUCT VARIABLES AND ITEMS

Construct	*Definition*	*Items*
PU	Perceived usefulness measures GADV/VE system functionality.	6
PEOU	Perceived ease of use measures health professionals' satisfaction about GADV/VE system usability.	3
ATU	Attitude toward usage measures health professional's feelings toward using GADV/VE system.	3
BIU	TAM theorises that BIU is a direct predictor for the acceptance and adoption of new technologies.	2
PhE	Researchers showed that users' personalities could impact their behaviours [25], it is suggested that physical and emotional [26] would be one of the constructs that may influence the users' behaviour in the VE. Physical and emotional measures if there is a physical or emotional hinder in VE that may affect health professionals' attitude toward using the system.	2
TA	The use of GADV/VE will give health professionals a different experience with the intent to engage and hold interest.. Technical aspect measures the health professionals experience regarding navigation and communication from the technical side in VE.	2
AHWH	The proposed work evaluated by in-house health professionals. This construct is to measure if the availability of the VRS lab is influencing the users' behaviour toward using GADV/VE.	2
Orient.	This construct measures how health professionals can execute specific tasks or manipulate through data with provided tools.	2

The relationships among the variables and the hypotheses are depicted in Fig. 6. The boxes represent the constructs which are measured by a set of items with arrows representing hypotheses H1a-7. The three constructs that reflect the items related to virtual environments in general (Technical aspects, Orientation, and Physical and emotional) are aligned together plus the availability of hardware in-house constructs which is added specifically to measure the importance of VRS Lab in-house.

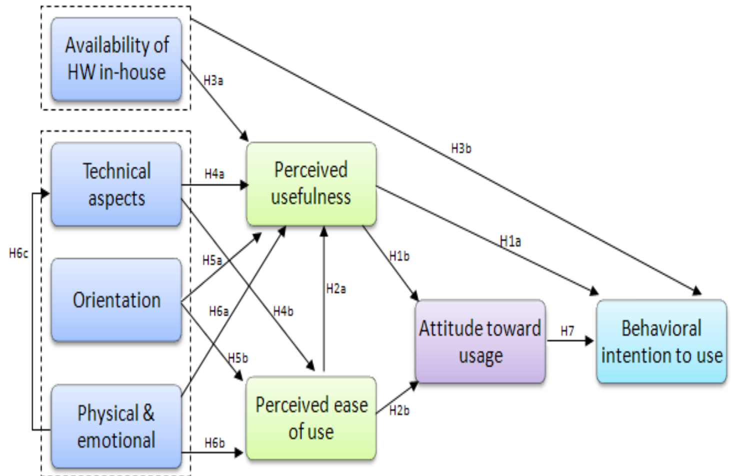

Fig. 6. Proposed Research Model for Health professionals GADV/VE system acceptance, showing the hypotheses between the constructs.

The extended model that adopts TAM relationships between constructs hypotheses includes the following:

- H1a: A user's perceived usefulness of a GADV/VE system positively affects his/her behavioural intention to use the system.

- H1b: A user's perceived usefulness of a GADV/VE system positively affects his/her attitude toward using the system.

- H2a: A user's perceived ease of use of a GADV/VE system positively affects his/her perceived usefulness of the system.

- H2b: A user's perceived ease of use of a GADV/VE system positively affects his/her attitude toward using the system.

- H3a: The availability of hardware in house (VRS Lab) positively affects the user's perceived usefulness of the system.

- H3b: The availability of hardware in house (VRS Lab) positively affects the user's behavioural intention to use the system.

- H4a: The easiness of technical aspects provided positively affects the user's perceived usefulness of the system.

- H4b: The easiness of technical aspects provided positively affects the user's perceived ease of use of the system.

- H5a: The orientation positively affects the user‘s perceived usefulness of the system.

- H5b: The orientation positively affects the user‘s perceived ease of use of the system.

- H6a: The physical and emotional positively affects the user‘s perceived usefulness of the system, (if users have no side effects from VE they would benefit more).

- H6b: The physical and emotional positively affects the user‘s perceived ease of use of the system, (if users have no side effects from VE they would feel at ease while using the system).

- H6c: The physical and emotional positively affects the technical aspects of the system, (if users have no side effects from VE they will not have any problems regarding technical aspects).

- H7: The user‘s attitude toward using the system positively affects his/her behavioural intention to use the GADV/VE system.

IV. RESULTS AND DISCUSSION

A. Study Population

User trials were conducted with 20 health professionals forming the user base, each with relevant experience specifically in the field of gait analysis; academic levels and experience varied between professor, reader, senior lecturer, lecturer, research fellow, research associate, or research student.

Before commencing each trial, demographic information was collected from each user, and each user was briefed with a trial descriptor. Consent was received for trials from the users before any data was collected.

Trials with the participants were conducted in the in-house VRS Lab, to test the idea of extracting data and visualising it in a virtual environment application, where data could be manipulated through the applications interface by the trial user in a practical evaluation.

Following the practical system evaluation users completed a questionnaire. This formed the basis of the TAM results, with users assessing values for 22 items grouped into 8 constructs. Values were applied from a 7-point Likert scale [27] (see Appendix).

B. Descriptive statistics and reliability

The constructs were assessed for reliability using Cronbach‘s alpha [28-29]. All the values for α were greater than the 0.70 minimum value required for constructs to be deemed reliable [30]. Moreover, all values for α were above 0.80, exceeding the common threshold value recommended [31]. All of the measures used in this work showed excellent internal consistency, ranging from 0.86 to 0.98, (see Table II).

TABLE II. DESCRIPTIVE STATISTICS OF ITEMS AND CRONBACH'S ALPHA

Constructs & items	*Mean*	*Cronbach's alpha*
Attitude toward usage (ATU)	**5.43**	**.97**
ATU1	5.35	
ATU2	5.20	
ATU3	5.75	
Perceived usefulness (PU)	**6.31**	**.90**
PU1	6.20	
PU2	6.45	
PU3	6.15	
PU4	6.45	
PU5	6.15	
PU6	6.45	
Perceived ease of use (PEoU)	**5.95**	**.98**
PEoU1	6.05	
PEoU2	5.85	
PEoU3	5.95	
Behavioural intention to use (BIU)	**5.65**	**.86**
BIU1	5.65	
BIU2	5.65	
Physical & emotional (PhE)	**6.27**	**.89**
PhE1	6.30	
PhE2	6.25	
Technical aspects (TA)	**6.12**	**.92**
TA1	6.10	
TA2	6.15	
Availability of hardware in-house (AHWH)	**6.07**	**.97**
AHWH1	6.15	
AHWH2	6.00	
Orientation	**5.67**	**.88**
Orientation1	5.45	
Orientation2	5.90	

The means for all constructs and items were determined (see Table 2). The highest mean (6.31) for perceived usefulness indicates that on the whole health professionals perceived the system to be useful. In the *perceived usefulness* construct the mean for the items PU2 and PU6 was 6.45, pointing out the importance of the provided technology.

The means for *physical and emotional, technical aspects, and availability of hardware in house* were 6.27, 6.12, 6.07 respectively, which shows that the users‘ answers were between strongly agree and moderately agree on the simplicity of technical aspects in the VE and the importance of having the virtual reality and simulation laboratory in-house. In *technical aspects* construct the highest mean was for the item TA2 with a value of 6.15, indicating that users found technical aspects in the VE were not complicated. In the *availability of hardware in-house* construct the highest mean was for the item AHWH1 with a value of 6.15, indicating that users found the availability of a VRS Lab in-house to be useful and they intend to use it frequently in the future. In the *physical and emotional*

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construct the highest mean was for the item PhE1 with a value of 6.30, demonstrating that within the time frame of operation of the user trial in the VE, adverse effects were negligible. The means for all other constructs were all greater than 5 (answers were between slightly agree and moderately agree) which indicates that users agreed on all items within the constructs.

In the *attitude toward usage* construct the highest mean was for the item ATU3 with a value of 5.75, showing that users found the VR system convenient and beneficial for visualisation. In the *perceived ease of use* construct the highest mean was for the item PEoU1 with a value of 6.05, indicating that users found the VR system easy to use, clear andunderstandable. In the Orientation construct the highest mean was for the item Orientation2 with a value of 5.90, indicating that users could manipulate data in the VE even if they had never used the system before. For the *behavioural intention to use* construct, the means were equal for both items BIU1 and BIU2 with a value of 5.65, suggesting that if such a system was available, users would intend to use the system frequently.

C. Hypotheses testing

Based on the aforementioned analysis, results confirm the existence of statistically significant relationships in the directions of the proposed research model. The results of the hypotheses tests are shown in Table III, using regression analysis. Overall, 13 out of 14 hypotheses were supported by the data; all hypotheses of the original TAM (H1b, H2a, H2b, and H7) were supported. *Perceived usefulness* had a significant effect on *attitude toward usage*, as well *perceived ease of use* on *attitude toward usage* (Davis, 1989; Hu et al., 1999); moreover, *perceived ease of use* had a significant influence on *perceived usefulness*, with p<0.01. (Statistically significant as p<0.05 and statistically highly significant as p<0.001, less than one in a thousand chance of given result occurring simply by chance).

TABLE III. CORRELATIONS BETWEEN THE CONSTRUCTS

Hypotheses	***Path***	***p-value (p)***	***Correlation coefficient (r)***	***Results***
H1a	PU → BIU	0.000	0.775**	Supported
H1b	PU → ATU	0.000	0.830**	Supported
H2a	PEoU → PU	0.000	0.806**	Supported
H2b	PEoU → ATU	0.013	0.543*	Supported
H3a	AHWH → PU	0.000	0.839**	Supported
H3b	AHWH → BIU	0.001	0.689**	Supported
H4a	TA → PU	0.000	0.772**	Supported
H4b	TA → PEoU	0.000	0.910**	Supported
H5a	Orient. → PU	0.028	0.491*	Supported
H5b	Orient. → PEoU	0.004	0.616**	Supported
H6a	PhE → PU	0.138	0.344	Not Supported
H6b	PhE → PEoU	0.024	0.502*	Supported
H6c	PhE → TA	0.001	0.673**	Supported
H7	ATU → BIU	0.002	0.652**	Supported

Furthermore, for the constructs added to test the users' acceptance for the system in VE, results show a strong direct influence of *technical aspect* on *perceived ease of use* (r= 0.910, p<0.01), *availability of hardware in-house* on *perceived usefulness* (r= 0.839, p<0.01), a moderately strong effect of *orientation* on *perceived ease of use* (r= 0.616, p<0.01), and *physical and emotional* on *technical aspects* (r= 0.673, p<0.01). On the other hand, one of the hypotheses was not supported as the *physical and emotional* did not have a significant influence on *perceived usefulness* (r= 0.344, p=0.138). The model and hypotheses were tested by examining correlation and significance, as shown in Fig. 7. Each arrow except for dotted arrows represents a statistically significant relationship between variables.

Overall, users had a positive attitude toward the proposed system; therefore they intend to use it and are satisfied with the tools provided.

Note. ** $p < 0.01$, * $p < 0.05$

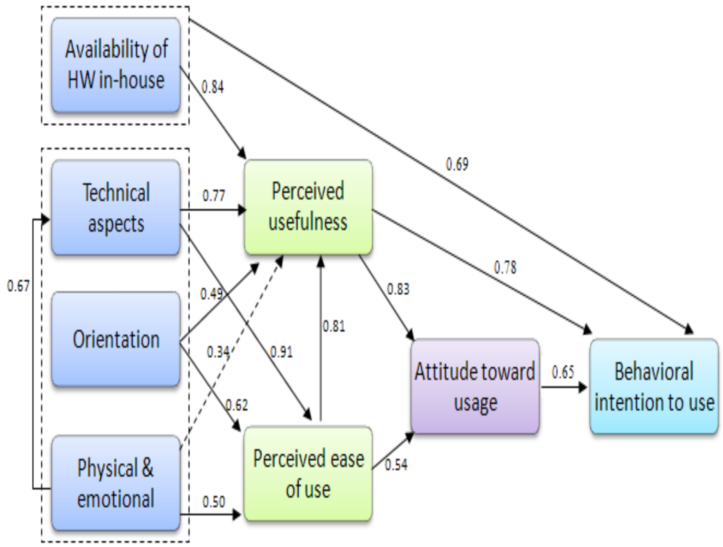

Fig. 7. Modified technology acceptance model with coefficient.

D. Discussion

Several important findings have emerged from this testing. Technical aspects of the system appeared to be a significant determinant of perceived ease of use and perceived usefulness, and an indirect effect on behavioural intention to use through perceived usefulness. This suggests that users found provided technical aspects in virtual environment are important for users to perceive system's usefulness and ease of use. Availability of hardware in-house has a significant effect on perceived usefulness and behavioural intention to use the system in the future, which shows the importance of having the VRS laboratory in-house for users. The orientation construct has a moderately strong effect on perceived ease of use and perceived usefulness, indicating that data manipulation functionality provided by the application's user interface positively affected the perceived usefulness and ease of use. This evaluation did not find a significant relationship between physical and emotional in the VE and perceived usefulness, but found that physical and emotional has a moderately strong influence on perceived ease of use and technical aspects, which indicated that side effects in the VE do not affect the perceived usefulness. Consistent with prior research [10, 33], there was a positive correlation between perceived ease of use and perceived usefulness of the GADV/VE system. This indicated that health professionals found the system easy to use, and the effort required for system operation, 3D manipulation, and interaction in the VE was comfortable. They perceived the usable system as being a useful tool with the potential of adding value to gait data visualisation. Findings from the study also indicate that perceived usefulness has a strong and positive impact on attitude toward usage and behavioural intention to use: as health professionals perceived the system to be useful, they acquired stronger behavioural intentions towards using the system. It is concluded that based on the TAM and extended factors, the findings suggest that the system was perceived as useful and health professionals' intentions to use the GADV/VE system were strongly affected by technical aspects and availability of hardware in-house and moderately affected by orientation and physical and emotional side effects.

Overall, it is concluded that for the added constructs, health professionals' intentions to use the GADV/VE system, were strongly affected by technical aspects and availability of hardware in-house, and moderately affected by orientation and physical and emotional side effects.

V. CONCLUSIONS

Gait analysis data visualization in virtual environment system have been proven to be very effective in enhancing the health professional's experience and increasing time efficiency compared to traditional methods used. The proposed system was built and evaluated via users' trials. Users' feedback results of the evaluation have indicated that the system design and implemented functionality aided users in successfully dealing with medical data. Questionnaire responses were encouragingly positive and indicated that the system was pleasant to use and relatively unobtrusive.

This study is a step forward in examining health professionals' perceptions in the usage of medical data visualisation systems in virtual environments presenting a positive attitude towards usage and their behavioural intention to use the system, evidenced when taking in consideration the extended constructs that test the items related to virtual environments and virtual reality laboratories for the TAM. Analysis of users' reactions to the virtual environment system via the TAM shows that this would be a valuable tool in the diagnostic stage of gait analysis.

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A. Orientation (VE Self-Efficacy)

		Strongly disagree			Neutral		Strongly agree	
1.	I would manipulate data in VE if there is no one to tell me what to do, or I had system manual for reference, & never used the system before	1	2	3	4	5	6	7
2.	It was interesting to try out the tools provided and manipulate data in VE	1	2	3	4	5	6	7

B. Availability of HW in-house

		Strongly disagree			Neutral		Strongly agree	
3.	I think having the VRS lab in university campus is helpful and will make using VR system easier	1	2	3	4	5	6	7
4.	Quick and easy access to the VRS lab adds value to the proposed system	1	2	3	4	5	6	7

C. Technical aspects

		Strongly disagree			Neutral		Strongly agree	
5.	I feel at ease and enjoyment in VE	1	2	3	4	5	6	7
6.	I learnt how to navigate and communicate with the virtual environment easily	1	2	3	4	5	6	7

D. Physical and emotional

		Strongly disagree			Neutral		Strongly agree	
7.	I have no side effects (nausea ...) while I'm in virtual environments	1	2	3	4	5	6	7
8.	Navigation and immersive experiment perceived my enthusiasm	1	2	3	4	5	6	7

E. Behavioural Intention to Use (BIU)

		Strongly disagree			Neutral		Strongly agree	
9.	Assuming I had access to the system, I intend to use the system to export data from C3D file and view it in VE whenever the system becomes available	1	2	3	4	5	6	7
10.	Given that I had access to the VRS Lab, I predict I would use it frequently	1	2	3	4	5	6	7

F. Perceived Ease of use (PEOU)

		Strongly disagree			Neutral		Strongly agree	
11.	Learning to operate system would be easy for me as well as to become skilful	1	2	3	4	5	6	7
12.	Learning to manipulate 3D model and interact with in VE would be easy to utilise, flexible and understandable	1	2	3	4	5	6	7
13.	Overall, I would find GADV in VE is easy to use, clear and understandable	1	2	3	4	5	6	7

G. Attitude toward Usage of VR

		Strongly disagree			Neutral		Strongly agree	
14.	Using VR system is convenient and enhance visualisation	1	2	3	4	5	6	7
15.	I find presenting my own data in VE is beneficial	1	2	3	4	5	6	7
16.	Overall, I enjoy using VR system	1	2	3	4	5	6	7

H. Perceived Usefulness (PU)

		Strongly disagree			Neutral			Strongly agree
17.	Using gait analysis data visualisation (GADV) in virtual environment (VE) would enhance data visualization	1	2	3	4	5	6	7
18.	Interactive visualisation in VE would enhance data presentation	1	2	3	4	5	6	7
19.	Using GADV in VE would improve investigation among specific cases between group members in VRS Lab	1	2	3	4	5	6	7
20.	Using VR system would make presenting complicated cases easier	1	2	3	4	5	6	7
21.	Switching between 2D/3D view for gait analysis data adds value	1	2	3	4	5	6	7
22.	Overall, I think extracting data from C3D and visualise it in virtual environment is useful	1	2	3	4	5	6	7