An Overview of Self-Adaptive Technologies Within Virtual Reality Training

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Abstract

This overview presents the current state-of-the-art of self-adaptive technologies within virtual reality (VR) training. Virtual reality training and assessment is increasingly used for five key areas: medical, industrial & commercial training, serious games, rehabilitation and remote training such as Massive Open Online Courses (MOOCs). Adaptation can be applied to five core technologies of VR including haptic devices, stereo graphics, adaptive content, assessment and autonomous agents. Automation of VR training can contribute to automation of actual procedures including remote and robotic assisted surgery which reduces injury and improves accuracy of the procedure. Automated haptic interaction can enable tele-presence and virtual artefact tactile interaction from either remote or simulated environments. Automation, machine learning and data driven features play an important role in providing trainee-specific individual adaptive training content. Data from trainee assessment can form an input to autonomous systems for customised training and automated difficulty levels to match individual requirements. Self-adaptive technology has been developed previously within individual technologies of VR training. One of the conclusions of this research is that while it does not exist, an enhanced portable framework is needed and it would be beneficial to combine automation of core technologies, producing a reusable automation framework for VR training.

Keywords: Virtual reality, Adaptive systems, Intelligent Algorithms, Training

1. Introduction

Previously no systematic study has been published on the use of self-adaptive systems for virtual reality training. As a result, it was unclear what self-adaptive methods have been applied within virtual training systems, and what these methods offer to the maintenance and capabilities of virtual training systems. This systematic overview aims to provide this insight which is important for researchers, engineers, developers and scientists.

This research provides a current overview of the use of self-adaptive, autonomous systems and data driven training within Virtual Reality (VR) based training environments. Adaptation can benefit several core technologies within VR including haptic devices, stereo graphics, adaptive content, scoring and assessment and autonomous agents. Adaptation can provide customised or personalised content for individually tailored learner-specific training for maximum learning efficiency.

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The use of VR is continually increasing with mobile, online and ubiquitous technologies for 21st century learning. In 2014 Google released a VR interface for smartphones and Facebook acquired Oculus Rift[a], a VR headset company for $2 billion. Children are introduced to VR at a younger age as an effective part of K-12 primary, secondary and higher education (Merchant et al., 2014). Worldwide, VR is used for everyday training hand-eye coordination and physical skills. VR is useful for physical skills training. Training with VR has been applied to many training disciplines including flight simulation (Ko et al., 2015), military (Khan et al., 2013), engineering, space, automotive and manufacturing (Novak-Marcincin et al., 2014).

VR software applications are experiencing demand for increased mobility, including pervasive, ubiquitous, and embedded features, providing virtual training over the Internet and ad-hoc wireless networks. This leads to increasing demand to deal with handling complexity and achieving quality goals at run time.

A current problem is that VR trainees all experience the same training routines, which are not customised to individual learning patterns. Yet every trainee learns in a different way and will require their training to focus on specific aspects of the tasks.

Conventionally, in order to adapt or re-configure distributed training systems, human supervision is required which is costly and time consuming. Automation can avoid this human supervision to reduce or avoid these costs (Salehie and Tahvildari, 2009).

There is currently no method defined to enable adaptive VR training. Currently there is limited research on customization of VR training to suit individual learners.

Self-adaptive VR could potentially make training more efficient and effective. VR training could be improved by incorporating autonomous, data-driven aspects to customise and automate training for individuals (Boulton et al., 2009).

A literature search was performed to identify existing publications, research and patents which were reviewed as part of this research overview. Medical subject headings (MeSH) terms were used to seach on the Medline (Pubmed) database. Additional keyword searches were conducted using alternative databases including IEEE Xplore, ASME Digital Collection, ACM Digital Library, Google Scholar and IET/IEEE Electronic Library (IEL) which produced further relevant titles. Patent searches using the European patent office (EPO) were conducted to identify existing intellectual property via the worldwide patent database. The results contained a larger number of academic research than commercial/industrial applications.

The main objective of this overview paper is to clarify the current use of self-adaptive systems and automation within virtual reality training and assessment. Adaptation within VR includes a variety of immersive, high fidelity technologies. Self-adaptation is particularly useful in VR for generation of learner-specific training scenarios to enhance learning. The paper will assess current applications for:

- Automating haptic feedback, for guiding novices based on expert knowledge.
- Automating VR training which can lead to automation of actual procedures such as robotic assisted surgery.
- Automating the generation of customised learning content in terms of visual, haptic and audio material to provide scenarios for learning which ideally challenge the individual in the best way to target improvement of their most beneficial skills.
- Automating the assessment and scoring mechanisms, which objectively generate feedback on a trainee's performance. This forms a vital part of generating user-centered content.

[a] https://www.oculus.com

The rest of the paper covers: section 2; outlining the principles of self-adaptive systems, which provides a precursor to adaptation of software since the main focus of this work is adaptation within VR training environments.

This review has been organised in such a way that sections 3 and 4 present the main bulk of this research. Section 3 details the five main technologies used within VR, by detailing the uses for these five technologies within VR, which are (i) adaptive technology, (ii) haptic devices, (iii) head mounted displays (HMDs), (iv) assessment and (v) autonomous agents. Section 4 presents five main application areas of VR training; (i) medical, (ii) industrial and collaborative, (iii) collaborative and Massive Open Online Courses (MOOCs), (iv) serious games and (v) rehabilitation. These five areas were identified by an increased number of publications in these focus area. This overview reports the state of art within each of the five main VR application areas. The application area of Medical VR is particularly active and has the largest number of publications over recent years, perhaps due to the potential benefits offered by VR in avoiding patient harm.

Other sections include section 5; covering the future VR technologies. Section 6 provides an overall comparison, which enables the reader to accessibly view which VR technologies have been used in which types of VR training. Section 7 draws conclusions from this overview summarising the current state and future directions of adaptive training in succinct form.

2. Principles of Self-Adaptive Systems

The definition of an adaptive system is a set of interacting entities that together are able to respond to changes. Examples of natural adaptive systems include ecosystems, organisms or human communities.

Feedback loops represent a key feature allowing response to change. In adaptive systems this loop is known as a control loop. Control loops in adaptive systems can be formed from four categories of machine learning: prediction, recognition, detection and optimization (Stenudd, 2010). The outputs from the previous loops often initiate the inputs to subsequent loops, primarily causing change in response to the internal and external environment context.

Often when the user's behaviour and related parameters change, it is the task of functional adaptation to identify methods to adapt the environmental behaviour in response. Virtual agents aim to adapt and improve their functions over time, machine learning is often the technique used to study approaches to achieve this. (Stenudd, 2010)

Software systems can be self-adaptive by applying closed-loop feedback with the aim to detect changes in operation and respond at run time by self-adaptation. Often the adaptations result from internal (self) or external (context) events. In order for software to adapt, it must observe its own context, to identify relevant changes, make decisions regarding appropriate reactions, and implement these decisions by taking action (Salehie and Tahvildari 2009).

Adaptive systems have been used within numerous subject topics and apply various theories and models. A survey of self-adaptive software was presented by (Salehie and Tahvildari, 2009).

The primary need for self-adaptive software stems from the growing costs of implementing software applications with highly complex objectives (Laddaga, 2000).

The requirements of self-adaptive software include fulfilling the requirements during run-time even in presence of unforeseen changes. To accomplish this, adaptive systems need to demonstrate resilience to a degree of variability, whilst maintaining ability to overcome deviations from expected context, still reliably achieving goals.

Manual management and adaptation of software takes time and has high cost, so the advantage of an automated adaptation mechanism is that appropriate actions can be taken without excessive costs and not taking too much time. This requires the software to monitor the environment, observe changes and choose suitable actions (Salehie and Tahvildari, 2009).

An IEEE standard was derived to cover maintenance of self-adaptive software in response to environment changes (IEEE-ISO/IEC 14764 2006). Self-adaptive systems can also fix their own run-time bugs.

Formal approaches to self-adaptation within software provide approaches to thoroughly identify behaviours of adaptive software and their explanations both at design time and run time (Weyns et al., 2012).

Generally self-adaptive systems comprise two sections: (1) dealing with domain functionality which is a managed system, and (2) adaptation which is a managing system, which modifies the managed system to achieve quality objectives (Weyns et al., 2012).

Self-managing software is closely related to self-adaptive software, sharing autonomic functions (Kephart and Chess, 2003) but there is no standard differentiation between these terminologies. Self-adaptive systems have less coverage than autonomic computing (Salehie and Tahvildari, 2009) and therefore can be regarded as a subset of autonomic computing.

Self-adaptive software can contain many subset capabilities including ability to be self-adaptive, self-managing, self-governing, self-maintaining, self-controlling, self-evaluating or self-organising.

Early adaptive systems in the mid 1990's used feedback loops with physiology (Byrne and Parasuraman, 1996). Research on affective computing has also developed adaptive software taking into account the user's emotions (Picard, 1995).

This section has detailed the principles of adaptive systems. The next section 2.1 will detail methods for generating customized VR training content.

2.1. Method for generating customized VR training content

Designs for autonomous VR training systems usually contain feedback loops to connect several elements. (i) Initially the trainee is presented with a particular task which the trainee could attempt to complete. (ii) For assessment on completion, the system assesses or scores the trainee's performance on various factors or modules. Assessment may include accuracy, time taken, or skill in particular aspects. (iii) The autonomous training system selects the next task to be presented to the user based on past performance, targeting the individual's training requirements at that time.

If a trainee pilot within a virtual flight simulator performs badly in certain weather conditions, the autonomous training system may focus on that type of condition for future scenarios, enabling the trainee to improve the weakness (Ko et al., 2015). However if a trainee performs better than expected the system may progress to more challenging scenarios. If a user repeatedly fails a task, the training may focus on strengthening the trainee's pre-requisite experience.

The desired behaviour of the autonomous system is to make informed decisions about the best next step for a particular user's training at a given time. There are several intelligent methods which could be used by the system to infer these decisions. For an autonomous system, data can provide a method of intelligent intervention to improve the efficiency of training. For this, data is required for each user's historical training results, providing a complete history of all scores for each task and module. As autonomous training will have been completed within a computer-based system, score histories should be readily available. An expert system approach or other computational intelligence techniques may then be applied to deduce informed decisions to select the most beneficial training modules for the given trainee at the current point in time.

Overall there are various aspects of automating VR training which include (i) Mechanisms for adaptive learning about a user's training requirements. (ii) Adaptive and reactive features to enhance trainee's learning efficiency. (iii) Autonomous training using simulation. (iv) Intelligent monitoring of a trainee's progress. (v) Various types of adaptive content can be included.

Section 2 has provided a precursor for this paper, clarifying uses and principles of adaptation within software. The main focus of this paper is adaptation within VR training environments. Contributing towards this, section 3 will provide a summary of state of the art technologies used within VR training, describing the applications each technology has been used for.

3. Core Technologies of Virtual Reality Training

This section outlines five technologies which are the core building blocks of VR-based training simulations:

(i) Adaptive technologies.
(ii) Haptic devices.
(iii) Head mounted displays.
(iv) Assessment and scoring feedback.
(v) Autonomous agents.

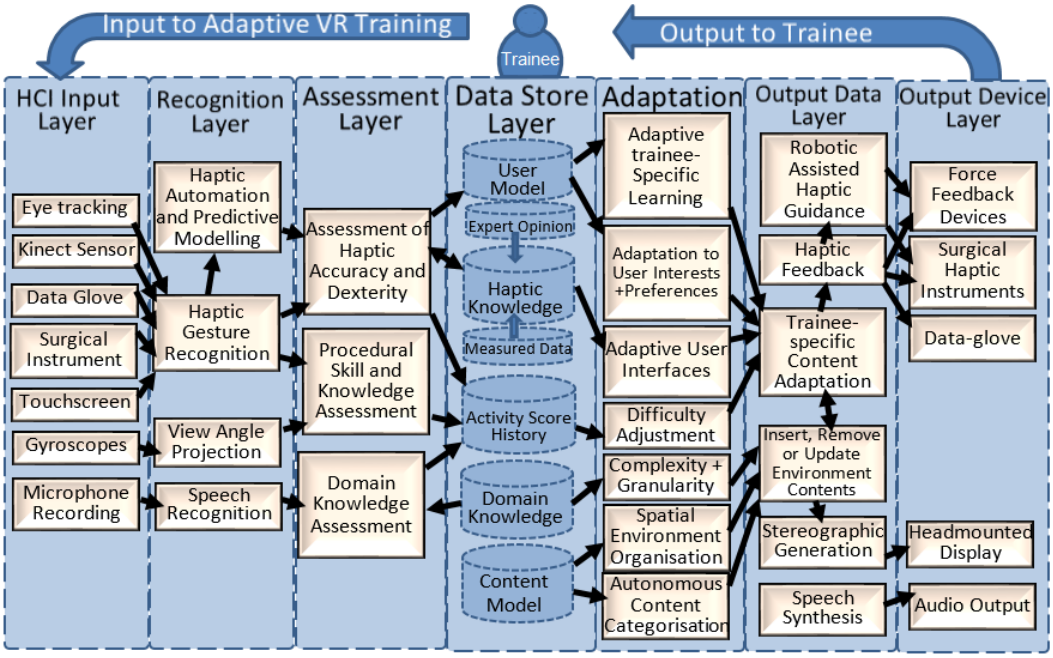

Fig. 1. Interacting structure of multimodal technology components within VR-based adaptive training.

Throughout the remainder of section 3, each of these five core technologies will be discussed in further detailed subsections. These five VR technologies are visualised in Fig. 1 showing the data flow and interaction with adaptation and various layers, building blocks for a unified hierarchical set of VR adaptive technologies. In the HCI layer, Kinect sensor may also represent other recent wireless gesture tracking devices such as Leap Motion. Non-core technologies are not covered by this article's scope. This overview outlines: (i) how each of these technologies are currently being used within VR training, (ii) how much adaptation has been applied to each technology, (iii) which topic areas of VR training each technology has been applied to, plus (iv) how these technologies have been combined together for multimodal VR. Each of the five core technologies influence adaptation of the VR training (Fig. 1.).

3.1. Adaptive Technologies for Training Content

Adaptation is one of the five core technologies in VR-based training, as shown in Fig. 1. Adaptation works with many data stores including the user model and score history, to provide a vital link connecting all technologies together. For example if the trainee interacts with an autonomous agent or haptic device, the stereo display output may adapt in response. The trainee's assessment score can take into account their eye tracking, motion capture and haptic device data, and adaptation will adjust the training difficulty to match skill level.

This section summarises the use of adaptive technology to generate user-centred VR-based training material. Figure 2 highlights the time-line of technology improvement within adaptive technologies used within VR-based training systems. The timeline gives an insight into the recent developments and highlights key research publications applying adaptation. Each timeline in this review represents key developments in the 12 years between 2004 and 2016. This timeline summarises the technology trend evolution, considering commercial, academic and patents.

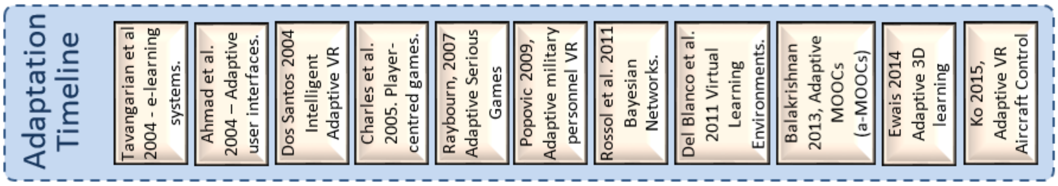

Fig. 2. Time-line of developed Adaptive Technology within VR-based training.

3.1.1. The History of Developments within Adaptive Training.

One of the earliest alternatives to rule-based learning was data driven learning (DDL) initiated by (Johns 1986, 1991). Conventional rule-based learning was not proving capable of enabling a machine to respond intelligently to linguistic question generated by students. DDL for linguistics in this context led to a change in the role of the teacher who became more a director of the student initiated learning.

Later, system architectures for intelligent virtual training were presented (Bouras et al., 2002). These were defined by user needs for collaborative and distributed virtual environment e-learning. However the customization was not based on a data driven intelligent approach. The learner's assessment scores were not used to target their weaknesses.

During 2004 e-learning systems were still in their infancy (Tavangarian et al., 2004). The learner was not yet individualised and was treated as a noncritical homogenous user. To overcome these drawbacks, it was realised that more advanced systems would need to generate individual e-learning materials. During this infancy stage, it was acknowledged that a flexible multi-dimensional data model and the generation of individual content could provide the solution, necessary to enhance smart interaction between learners and content in e-learning systems.

Since then, adaptive user interfaces started to become a core part of VR-based training. Adaptive user interfaces require domain knowledge to be presented in a context-oriented, intelligent method. The granularity and complexity of domain knowledge adaptation should be a suitable match for the trainee's skills (Ahmad et al., 2004).

An adaptive and intelligent virtual environment was presented (Dos Santos and Osório, 2004), which is presented and structured based on a model of trainee preferences. This is achieved by inserting, removing or updating the environment contents. Autonomous content categorisation is used to create models of the contents and used for spatial organisation of the environment, which began to show promising advantages from the use of adaptation (Dos Santos and Osório, 2004).

Subsequently, trainee-specific learning was adopted in digital games for designs with player-centred adaptive modelling (Charles et al., 2005). Game designs using player-centred adaptive modelling technologies were able to facilitate matching the difficulty level and learning curves to suit the individual player based on gender, age and skills which enhances the gameplay feeling for each player (Charles et al., 2005).

More recently, Bayesian network systems have proven effective for automated adaptive training in virtual rehabilitation (Rossol et al., 2011). Investigations may be necessary to assess whether this approach can apply to other virtual training.

Recent increased recognition of Virtual Learning Environments (VLE) for use within e-learning raises other complications including the fabrication of student-centred modules which autonomously adapt to individual student requirements (Del Blanco et al., 2011). Middle-ware has been developed for (i) adaptation and (ii) assessment within virtual learning by stealthily tracking activity of learners, to produce accurate user models or enhancing the assessment. (Del Blanco et al., 2011).

Recently more advanced adaptive 3D learning environment systems have been emerging which dynamically adapt to the learner (Ewais and Troyer, 2014). The adaptation also responds to activities which the learner conducts during the training.

Following the progress of adaptation, conventions in learning have started to change. The syllabus is becoming less centralised. These changes have brought about questions: Can the adaptive learning methods be combined with traditional learning methods? How far can the learner progress with adaptive learning in a particular educational setting?

3.2. Head mounted displays (HMDs), Stereo-graphics, eye and head tracking.

With conventional flat monitor screens the lack of depth perception is a limitation to VR realism. A variety of technologies have recently been used to enable the generation of stereo images including holographic displays, head mounted displays, OLED screens and shutter glasses.

Head Mounted Display (HMD) systems often work in parallel with head motion tracking or eye tracking for enhanced realism. HMDs are often both an input and an output device. Inputs can include head motion tracking sensors, eye motion tracking, gyroscopes and accelerometers. The outputs are the two graphical displays, one for each eye. These inputs provide context-rich data which could be analysed by computational intelligence algorithms to spot behaviour patterns within the data. This information could be used for adaptation to produce adaptive content to personalise the experience for each user.

Stereo displays can be automated with calibration using neural networks or optimisation algorithms (Chen et al., 2014).

Figure 3 highlights the time-line of technology improvement within head mounted displays or stereo graphics used within VR-based training systems.

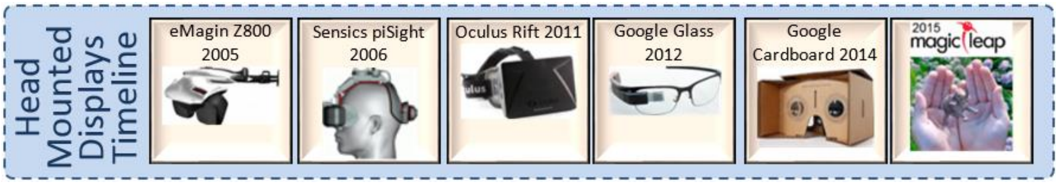

Fig 3. Time-line of developed HMDs for VR-based training.

3.2.1. Medical VR applications for Head Mounted Displays (HMD).

As a medical technology tool, head-mounted displays, tracking and cueing systems have proven useful for over two decades. Early HMDs have been used to assist with rehabilitation (Rushton et al., 1996). Later HMDs were used for the assessment of patients suffering problems with sight loss and vision problems, such as hemi-neglect, a condition where patient’s only notice stimuli from one-half of the visual field either right or left (Myers and Bierig, 2000).

Clinicians have benefited from using HMDs for superimposing CT scan augmented bones or organs onto a patient’s body (Fichtinger et al., 2005). More recently HMDs have been used to overlay partially transparent augmented reality x-ray or MRI directly onto the patient’s body (Erat et al., 2013).

3.2.2. State-of-the-art HMD stereo devices.

In 2015 Microsoft announced HoloLens [b], an augmented reality headset. The device augments a holographic world projected in front of peripheral vision. HoloLens only takes up a small field of vision and uses voice and gesture commands. The headset supports HoloStudio which can aid 3D CAD design by projecting an augmented model which can be modified by hand gestures prior to 3D printing.

The Oculus Rift headset was designed for VR rather than augmented reality (AR) because it takes up the full field of view, unlike HoloLens which was designed for AR. Oculus Rift is compatible with computers, but a development kit could enable the device to be ported to Android, which would provide compatibility with many tablets and smart-phones which are becoming capable of running VR software.

Magic Leap has been funded $542 Million by Google in 2014 (Forbes, 2014). It is developing an augmented reality headset combining fibre-optic projectors, lenses and cameras and is described by the CEO as "the most natural and human-friendly wearable computing interface in the world" (Forbes, 2014). Magic Leap has filed patents which reveal that the headset creates 3D patterns of light rays or light fields, allowing eyes to focus on depths of an artificial 3D scene just as they would in reality, providing a more realistic illusion of virtual objects merged with the real world.

Leap motion, founded in 2010 produce a small peripheral hardware sensor device that supports hand and finger motions as input requiring no hand contact or touching. It uses two monochromatic IR cameras and three infrared LEDs. Leap motion can be combined with Oculus Rift to produce an interactive virtual environment by mounting it onto the front of the HMD or placing it on a desktop.

Intel has released laptops and tablets in 2014 with a 3D sensor in place of the webcam. A second 3D sensor at the rear side can create 3D scans of people or items over twelve feet away to capture the colour and 3D profiles of the environment. This could enable a device to detect hand signals or locate items. The sensor could have uses for online clothes shopping whereby the sensor could use a 3D photo of a user to get an accurate measurement of clothing or shoe size. The sensor could allow tablets to measure the dimensions of furniture in a store, and display how it would fit into the customer's living room. Also the tablet's 3D sensor can be used to build augmented reality game software. Virtual objects of creatures displayed on the screen can integrate with the actual background.

Microsoft HoloLens is targeting a new era of human computer interaction (HCI) based on gaze, gesture, touch or voice recognition. Hands-free interfaces may become the successor to touchscreens, which were made ubiquitous by Apple. Nissan, Ford and Audi have introduced a gesture-controlled Kinect based system for dealerships enabling vehicle buyers to look inside a virtual new car (MSDN, 2012).

GestSure is a start-up based in Seattle selling a product based on Kinect allowing surgeons to use gesture control to display medical images and scans. Referring to scans is crucial in the operating room but surgeons can't touch any controls due to sterilisation.

Hackers have shown enthusiasm to take the Microsoft Kinect and repurpose it for different uses such as robot navigation or controlling a web browser (IEEE, 2014).

Google Cardboard offers a virtual reality headset for smartphones which can be built at home from household objects and attached for VR experience.

3.2.3. Negative effects of Head Mounted Displays (HMD).

Negative after-effects and reduced hand-eye coordination can temporarily occur after using a head mounted display (HMD). There is evidence that see-thru HMD can alter hand-eye coordination leading to increased discrepancy in comparison to baseline hand-eye accuracy. Decreased hand-eye accuracy of HMDs could cause negative effects for surgery trainees who rely upon high accuracy hand-eye coordination (Rolland

[b] http://www.microsoft.com/microsoft-hololens

et al., 1995). Users can partially adapt to most altered perceptual environments.

Motion sickness has historically been a problem with HMDs (DiZio et al., 1992). This may have been eliminated from the new Oculus Rift headset, which was acquired by Google for over $2 Billion in 2013. Twenty years earlier in 1993 the Sega Genesis VR project released a headset combining VR graphics with movement tracking software. This triggered motion sickness because the graphics followed the movement of the user's head with a noticeable time delay. Most modern headsets refresh at 125Hz, but the newest model of Oculus Rift headset refreshes at 500Hz with lower latency and no motion blur. Some users report motion sickness is eliminated, although a thorough trial may be required to confirm this. Also motion sickness can result from postural stability being reduced during a simulation (Smart et al., 2014).

Motion capture and tracking footage of actors produces more realistic humanoid CGI movement animations rather than pure animations alone. This helps to avoid the 'uncanny valley' problem which describes how poorly animated VR near-human CGI animations prompt discomfort in viewers. The 'uncanny valley' problem was discussed in a recent review (Tinwell et al., 2014). As virtual reality worlds become more visceral, and as users report the feeling of deep immersion becoming more pronounced, the more likely users are to experience the unnerving sensations resulting from poorly animated motion of VR humanoids.

3.3. Haptic Devices for VR-based Training

Haptic feedback is used within VR to train tactile skills, making VR especially useful for learning physical skills where feeling and touch are important. A large variety of haptic force types can be fabricated including torque, vibration, resistances. Forces can be applied in multiple of degrees of freedom (DoF), commonly 3, 6 or more. The frequency of vibro-tactile feedback affects how haptic sensations feel to the user and can be adjusted within various bandwidths; the common frequencies range from 100Hz to 500Hz (Ko et al., 2015).

High precision scientific haptic instruments are becoming more widely available. General purpose devices are available from SensAble, now known as Geomagic[c], Novint[d], or Force Dimension[e]. A comparison is shown in Table 1. Haptic devices have often been custom designed for particular training applications using motors with gears, electro-magnetic or electro-static forces for vibration (Ko et al., 2015) or by modifying existing haptic devices such as Novint Falcon (Coles et al., 2011). Smartphones and tablet devices can now support a variety of tactile effects using libraries such as the Immersion Haptic SDK[f].

Table 1. Comparison of features of consumer haptic devices (Coles et al., 2011).

Company	Haptic Device	Movement size (cm)	D.O.F	Maximum Force (N)	Max. Torque (mMm)	Force D.O.F	Cost
Geomagic	Premium3.0	41 x 58 x 84	6	22	515	6,3	£45000
	Premium1.5	19 x 27 x 38	6	8.5	515	6,3	£20000
	Premium1.0	13 x 18 x 25	6	8.5	0	3	£15000
	Desktop	16 x 13 x 13	6	7.9	0	3	£9000
	Omni	16 x 12 x 7	6	3.3	0	3	£1700
Force	Omega3,6,7	16 x 16 x 11	3,6,7	12	8	3	£12000
Dimension	Sigma7	19 x 19 x 19	7	20	400	7	£52000
	Delta3,6	36 x 36 x 30	3,6	20	200	3,6	£19000
Novint	Falcon	10 x 10 x 10	3	9	0	3	£200

[c] http://www.geomagic.com/en/products-landing-pages/haptic
[d] http://www.novint.com
[e] http://www.forcedimension.com
[f] http://www.immersion.com/developers

Figure 4 highlights the time-line of technology improvement within haptic devices used within VR-based training systems.

Fig 4. Time-line of developed haptic devices for VR-based training.

Several libraries are available to control the most commonly available haptic devices. Such libraries are described in the review by (Deng et al., 2014). The commonly available libraries are shown in Table 2.

Table 2. Current libraries for haptic device Application Programming Interfaces (APIs).

Library Name	Supported Haptic Device(s)	Programming Language(s)
Open Haptics	SensAble	C++
CHAI 3D	Supports numerous manufacturers including VR systems.	C++
H3DAPI	Geomagic, Novint, X3D	C++, Python
Reachin API	Hardware Independent	C++, VRML, Python
HaptX	Novint, SensAble	C++
HAPTIK	Supports numerous manufacturers	C++, Java, Matlab, Simulink
Virtual Hand	Cyber Glove Systems, Virtual Hand	C++

3.3.1. Adaptive systems for Haptic Devices.

Adaptive technology is useful within haptic feedback. When an expert uses a haptic device for performing a task within a virtual simulation, the movement of the haptic controller can be recorded during the expert's performance of the procedure and stored as expert knowledge. The expert knowledge can be replayed as haptic guidance so that novices can observe and feel how an expert performs a procedure.

Haptic devices including data-gloves can be automated by neural network predictive modelling to recognize gestures (Luzanin et al., 2014).

Haptic devices recently utilise automation and predictive modelling (Yamashita, 2014), to provide increased tactile realism such as resistance on airplane controls (Ko et al., 2015), or predictive control on a car steering wheel (Yamashita, 2014). Haptic automation and predictive modelling could enable assistive technology which takes control of a vehicle to avoid accidents, or fully drive unmanned vehicles. Automated vehicles are expected to increase the demand for transport to more than triple by 2050 (Offer, 2015). Automation in aircraft control is already common through autopilot systems monitoring data from dynamic aircraft sensors and controls, which often surpasses the performance achieved by pilots (Olivari et al., 2014).

Haptic training systems aim to adapt a user's physical skills to match an ideal performance. This ideal performance benchmark is often formed from analysis of an expert performance. Learning hands-on skills from a haptic simulator enables the system to adapt a user's physical and tactile methods of the procedure. The adaptive elements of a user's physical skills can be measured in terms of the angle, force or rotation of the haptic instruments.

Omni-Directional Treadmills (ODTs) use adaptation within VR for walking or running (Chauhan et al., 2014) and intelligent fuzzy controllers (Khan et al., 2013).

3.3.2. Remote Haptic Interaction.

For remote haptic interaction, data-gloves enable tele-presence enabling users to feel artefacts in remote environments, or virtual artefacts in simulated environments.

Haptic devices have been applied to control remote surgical procedures and collaborative virtual surgery training (Gunn et al., 2005). In remote haptic training, the instructor can provide a haptic guiding hand, to manually assist the trainee.

Automated predictive or assistive haptic intervention can be generated from expert knowledge. Predictive algorithms in surgical simulators can instruct haptic devices to intervene avoiding accidents. Automated assistive haptic interventions could be transferred from VR to real surgery avoiding injuries in actual procedures.

3.3.3. Robotic Assisted Surgery with Haptic Feedback.

Robotic and computer-assisted surgery can assist both simulated and actual surgical procedures. Robotic-assisted surgery has good potential for improving accuracy and dexterity of surgeons and reducing patient injury. Integration of robotic control in human surgery has raised ethical considerations, yet benefits of robotic assistance have been proven. Surgical procedures integrating robotic assistance result in reduced problems, difficulties and deaths and increased unproblematic discharges (Yu, 2011). However, clinical success is not yet widespread and success is marginal. The reason may be that the surgeon requires more force and tactile feedback. There are technical challenges for robot-assisted surgery haptic feedback (Okamura, 2009).

Robot-assisted minimally invasive surgery (RMIS) can help to reduce the drawbacks of minimally-invasive surgery and to increase the surgeon's ability to perform surgical procedures.

Assistive technology is a step towards a fully autonomous system, which can perform the action without the need for a human to be present. Full automation could in future become a possibility for various surgical haptic interaction tasks and adaptive technology may contribute to that as it has for vehicle and other automation.

Tele-surgery and surgical tele-operated master-slave robots aimed at minimally invasive surgery (MIS) have been enhanced by additional forces and other sensation feedback while controlling robotic devices remotely. For virtual training, force sensations form vital parts enabling safe operation. Recent tele-surgery systems are becoming multimodal by combining eye tracking and haptics, such as Telelap Alf-x (Stark et al., 2012). Multimodality does help surgeons to locate target tissue (Deng et al., 2014) and experiments show a shorter average operation time compared to conventional tele-surgical systems (Despinoy et al., 2013).

3.3.4. Haptic Devices for medical training

Haptic VR is now more accepted as an advanced method of learning minimally invasive surgery (MIS) (van der Meijden et al., 2008). Haptic feedback within VR is most valuable throughout the acquisition of psychomotor skills (van der Meijden et al., 2008). A review of haptic MIS simulators found that the majority demonstrate optimistic evaluation of force feedback and it's benefits (van der Meijden et al., 2008).

A trial demonstrated benefits of force feedback for virtual learning, showing that in a simulator with haptic feedback novice surgeons performed on average 36% faster and 97% more accurately than without. Performance is enhanced by haptic feedback reducing cognitive load which is beneficial in surgery (Cao et al., 2007).

With surgical training, the angles of haptic interactions are critical for success of the training procedure. An example highlighting the importance of angulation accuracy in surgical haptic training is epidural needle insertion simulators. During an epidural procedure a few degrees of angulation makes the difference between correct placement, or collision with bone or accidental puncture. In hip surgery simulators, the angular placement of the acetabular cup is ideally positioned with 15º anteversion and 40º abduction. Inaccurate angulation increases the risk of hip dislocation which would require a second correctional surgery.

Haptic devices can use adaptive technology to assist the trainee to accomplish accurate angular or motion positioning by incorporating expert haptic guidance, which can adapt or reduce as the user's experience increases (Bayart et al., 2005).

3.4. Assessment and Scoring Feedback

Quantitative and qualitative assessment and scoring feedback is essential for several purposes: (i) To enable trainees to understand their performance. (ii) To enable adaptive systems to automate user targeted training content.

Figure 5 highlights the time-line of improvement for assessment and scoring within VR-based training.

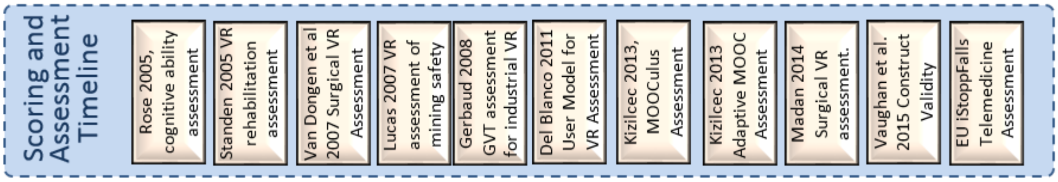

Fig. 5. Time-line of developed assessment and scoring within VR-based training.

3.4.1. Problems for Scoring and Assessment within VR Training

There are inherent problems with conventional assessment for medical trainees in which decision aids have been used to provide scoring (Wyatt et al., 1991). One problem with traditional assessment is that it does not account for diverse learning manners of individuals (Worthington et al., 1995). Inventory types based on Myers-Briggs can recognise learning methods and use that information to select the most efficient training activities (Worthington et al., 1995). The typology of Myers-Briggs can indicate trainees with varied backgrounds benefit from varied training styles, yet this approach has previously required manual intervention which is time consuming and laborious.

Real time error detection is a capability which generates feedback during the training. This is achieved by error detection methods which provide hints to the user as soon as errors are made. This could be a better method to intervene in real-time, as otherwise an error would not be known until the end of simulation. An example is (Chu et al., 1995) a training system for satellite controls.

3.4.2. Adaptive systems for Scoring and Feedback

Adaptive systems can be used to automate scoring and feedback, taking into account the trainee's performance within VR scenarios based on objective scoring criteria. Automated assessment provides an unsupervised and unbiased scoring mechanism and could be incorporated into curricula, replacing physical exams.

Adaptive systems can use assessment scores to adapt to an individual's learner-specific requirements by modifying the training packages presented to each user.

Adaptive VR training can control the extent to which feedback, hints and tips are displayed to the user in real-time. This can result in progressively decreasing the assistive technology as the trainees gain experience. In some cases, the initial training scenarios contain extra feedback, and the intervention gradually decreases when each learner moves forward through learning tasks and becomes more experienced. An example of this is the interactive virtual agent 'Steve' (Rickel and Johnson, 1999). Virtual agents can assist with teaching physical training to students. Steve shakes his head as a signal when mistakes are made, providing instantaneous feedback to assist the trainee in real-time.

3.4.3. Construct Validity.

VR training has been shown to possess two useful features: (i) It can assess and score a user's skill level (construct validity) (Vaughan et al., 2015a) and (ii) it may transfer to improvement in the real world (transfer validity) (Vaughan et al., 2015b).

Construct validity is a determination based on how much an assessment measures the concept it aims to measure, within the intended scenario based on measurements (Wanzel et al., 2002). There is very strong evidence for construct validity within VR simulators as they have proven to reliably assess the skill levels of trainees. This has been demonstrated for orthopaedic surgeons (Vaughan et al., 2015a), in which simulators can clearly differentiate between novices and experts based on their simulator performance (Van Dongen et al., 2007). This provides strong confirmation suggesting virtual simulators reliably and accurately provide scoring or assessment of trainees. In this way, simulators deliver an unbiased objective scoring method for residents, which can highlight topics each individual could develop in their technique (Vaughan et al., 2015a).

3.4.4. Transfer Validity.

Transfer validity refers to an ability of skills attained within VR simulation to transfer to improved skills in the real world.

Currently virtual surgery simulators provide some proof that they can teach skills which can transfer into improved skill on actual patients (Madan et al., 2014). It has been demonstrated by a few studies that simulator learned skills can transfer into real life scenarios (Dawe et al., 2014). Overall there is a positive opinion and acceptance amongst surgeons that VR training does improve in-vivo skills, which is generally revealed by increasing use of VR training for a variety of surgical procedures. Transfer validity is not conclusively demonstrated by studies at present.

More studies should thoroughly assess simulator transfer validity of and test transfer of specific skills, e.g. simulator-acquired surgical skills to the operating room. Transfer validity is difficult to test. In order to conclusively ascertain whether or not improved skill on actual patients can result from practice in virtual training, additional randomized controlled trials should be conducted to monitor trainee skills after and before virtual simulator training (Vaughan et al., 2015b). This should entail direct comparison between training on simulators and training with patients (Dawe et al., 2014).

3.5. Autonomous Agents

Autonomous agents within virtual training are computer rendered animated characters. They can act as embodied conversational agents (ECAs), intelligent virtual agents (IVAs) or embodied pedagogical agents (EPAs). Autonomous agents are increasingly used to enable interaction with the trainee within VR training. Agents interact with the trainee inside virtual environments to aid or adapt the user's interaction with learning content.

Figure 6 highlights the time-line of improvement for autonomous agents within VR-based training.

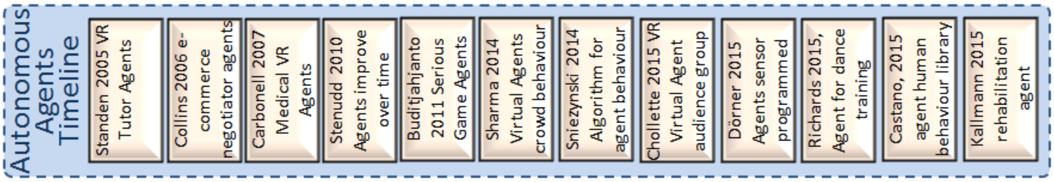

Fig. 6. Time-line of developed autonomous agents within VR-based training.

3.5.1. Autonomous Agents Simulating Human Behaviour within VR Training

Autonomous agents within virtual training can emulate human behaviour with recent libraries providing diverse sets of behaviour characteristics (Castano, 2015). This improves upon previous autonomous agents which were limited to a single aspect of behaviour. The motion and emotion emulation of autonomous agents is increasingly human-like and realistic such that autonomous agents provide virtual training for fine dextrous motor functions such as dancing (Richards, 2015), (Uejo, 2012). One approach for obtaining realistic, human-like motion is programming autonomous agents by direct demonstration using data recorded from actors or experts (Dörner, 2015). Autonomous agent behaviour for training can be programmed using sensor data, gross movement algorithms, path determination, collision avoidance and pedagogical temporal triggers (Gupta, 2012). Emotions of autonomous agents are becoming realistic to provide intuitive communication and psychologically believable agents. Autonomous agent emotion models use psychological theories or internal emotion models such as the Zurich model of social motivation (Schönbrodt, 2015). Various algorithms have recently been defined to control autonomous agent behaviour (Sniezynski, 2014). Machine learning can enable autonomous agents to increase their performance as their experience grows (Stenudd, 2010).

Digital human modelling is increasing used within VR and is useful for autonomous agent modelling. The IOWA Interactive Digital-Human Virtual Environment (Yang et al., 2004) introduced the use of kinematic digital human modelling within VR.

3.5.2. Crowd-based Multi-agent VR Training

For crowd-based virtual training, autonomous agents driven by defined rules can control crowd behaviour, such as in a virtual reality training environment (VRTE) for subway disaster evacuation using a head-mounted display (Sharma et al., 2014). Autonomous agents were used for crowd simulation and human behavior models during virtual aircraft evacuation training. Agents in groups or crowds can interact with each other, avoid obstacles and evolve to the environment (Hocevar, 2012). A crowd of autonomous agents was used in a recent virtual training simulator for public speaking to familiarise trainees with speaking to audiences (Chollet et al, 2014. Agents in audience groups can display feedback depending on behavioural descriptors correlated with the trainee's performance analysed using audio-visual sensors with a distributed modular architecture (Chollet et al, 2015).

Networked autonomous agents can contribute to robust, complex distributed training systems or MOOCs by interacting with humans or other agents. Self-adaptive collaboration patterns can provide autonomic features made up of ensembles of cooperating autonomous agents (Cabri et al., 2011). Collaborating agents can make decisions resembling networks of tasks with chronological and sequential limitations (Collins et al., 2006).

3.5.3. Other VR Training with autonomous agents

Autonomous agents can provide a viable alternative to lecturers in online training courses (Li et al., 2015). Autonomous agents can collaborate and share knowledge to replace missing team members in collaborative virtual environment for training (CVET) (Lopez et al., 2014).

Within adaptable VR training multi-agent systems such as Pegase, adaptable pedagogical agents can make informed decisions based on sets of represented knowledge to provide instructive assistance to trainees (Buche et al., 2010). Autonomous agents can advantageously influence learning of educational content (Clark and Mayer, 2011), (Krämer and Bente, 2010). Agents support face-to-face interaction and have been extensively applied to Virtual Learning Environments (VLE) and computed Intelligent Tutoring Systems (ITS) and that utilize immersive head-mounted displays or virtual reality rooms (Dede, 2009). Unlike human tutors, VR agents can be infinitely patient and consistent (Standen et al., 2005). Intelligent agents can act as pedagogical assistants to interact with trainees within a distributed virtual training system in order to facilitate training (Bouras et al., 2000).

As early as in 1999, an autonomous agent named Steve was developed to help trainees perform physical procedural tasks (Rickel and Johnson, 1999). The student and the agent co-habit a 3D simulated environment. The autonomous agent demonstrates how to perform tasks, monitors trainees during training, and provides help input if required. The agent's architecture includes awareness, reasoning and motion planning. The awareness of the VR environment creates an accurate model, providing data for the reasoning and motion planning. Reasoning helps to decipher detected external cues, identifying optimum motion plans, builds task lists to reach objectives, and generates movement instructions. Motion planning utilises movement instructions, initiating the agent's speech, motion, eye direction plus other signals enabling the agent to interact with virtual items (Rickel and Johnson, 1999).

3.6. Multimodal Technologies Combination

The five core VR technologies highlighted in previous sections can often interact together in various ways as shown in Fig. 1. Multimodal technology is becoming increasingly important within VR. Multimodal technology aims to achieve a multisensory, immersive and highly visual VR environment, for example combining quadrophonic audio with stereo graphics and haptic feedback. Each of these technologies can involve adaptation.

An example is multimodal driving simulators which combine eye tracking with haptic controls and steering wheels. Eye-tracking during driving is used to analyse the driver's attention hotspots, detect driver fatigue to assist the driver's safety. Eye-tracking enables comparison of novice and expert drivers (Horng et al., 2004).

Multimodality is described as a hew horizon for training. "Multimodal virtual reality enhances the effectiveness of learning from multimodal sensory integration" (De Freitas et al., 2006).

Another example of multimodal technology is visio-haptic interaction (Coles et al., 2011). Eye tracking has been combined with haptics which has been outlined as a new horizon in learning based serious games.

A multimodal simulator training system for needle insertion (Sutherland, 2011) describes combination of haptic feedback with camera tracking system (MicronTracker[g]), plus augmented reality 3D model on a computer screen. However the system does not demonstrate any automation in terms of haptic feedback, customised training or individual adaptation.

Multimodal minimally invasive surgery (MIS) tele-operative systems have combined eye tracking with haptics (Stark et al., 2012). Experiments show that multimodality helps surgeons to locate target tissue (Deng et al., 2014) and reduces average surgery time compared to conventional tele-surgery (Despinoy et al., 2013).

Multimodal interaction is used in smartphones. Eye tracking has been used to detect "gaze gestures as an input method, combined with vibro-tactile feedback as confirmation of the gaze event" (Kangas et al., 2014).

A review outlined innovative applications combining haptics with eye tracking for serious games (Deng et al., 2014). Combining several modalities can engage the human mind's ability to handle multiple inputs simultaneously. The trainees are then being exposed to other learning material instead of writing and images. Higher quality of data input media improves the accuracy to ensure learning.

Section 3 has provided an overview of 5 core technologies used with VR. These VR technologies have been applied to a variety of topic areas within existing VR-based training systems. These 5 main VR topic areas will be highlighted in Section 4.

4. Existing Virtual Reality Training Systems

This section presents a review of existing virtual reality training systems and their technological features. The simulators are arranged within a variety of topics, the main 5 VR-based training topics covered in this section are:

(i) Medical VR.
(ii) Industrial and Commercial VR.
(iii) Collaborative VR and MOOCs.

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[g] http://www.claronav.com/microntracker

(iv) Serious Games.
(v) Rehabilitation.

The five main VR topic areas shown above are covered in the following subsections, detailing their use of adaptation, current state-of the art, and outlining the ways in which these five VR topics make use of the five key VR technologies detailed in section 3.

4.1. Medical VR-based Training

Virtual reality has provided a paradigm shift for medical training (Gallagher et al., 2005). Medical training simulators have been developed for many procedures. Simulation-based medical education (SBME) includes simulators with various levels of fidelity. High fidelity simulators contain technology based physiological qualities such as blood pressure or heart rate, which react to physical involvement, covered in a review over 34 years (mcGaghie et al., 2010).

4.1.1. Features of Medical VR Training.

Important features of medical VR training include (i) assessment and scoring; (ii) repeated task training; (iii) integrated syllabus; (iv) measuring effects; (v) simulator realism; (vi) learning and conserving skills; (vii) training experts; (viii) improvement of actual skill; (ix) group training; (x) learning environment (mcGaghie et al., 2010).

Medical VR training often include haptic devices to train physical procedures, which range from very strong bone drilling in orthopaedics, down to sensitive soft tissue needle insertions (Kapoor et al. 2014). Also skills such as palpation of tumors have been simulated with VR training (Alhalabi et al. 2005).

3D virtual worlds (3DVW) have been used for medical training since 2000 and most frequently since 2006 (Ghanbarzadeh et al., 2014). As well as uses in academic and professional education, 3DVW are used for evaluation, plus actual treatment.

4.1.2. Benefits and Effectiveness of Medical VR Training.

A review based on 609 studies with 35,226 trainees found that the use of simulators enhanced by technology for healthcare training often results significant improvement of skill, knowledge, behaviours and can positively affect the patient outcome (Cook et al., 2011).

Assessment of skills within VR medical training can be a useful way to automate the trainee's performance feedback process and to inform which aspects of the VR need to adapt (Ahlberg et al. 2007).

Crisis situations and medical emergencies management are especially suited to simulator training. With conventional training it is rare for emergency cases to arise (Merién et al., 2010). Simulators allow unlimited practice in a safe, environment.

For nursing, a systematic review quantified the advantages of high fidelity simulators over other teaching methods in some contexts (Cant et al., 2010).

Team training in simulators can be beneficial for medical topics as long as the optimum team size is selected (Cant et al., 2010).

High fidelity medical educational simulators offer several advantages (Merién et al., 2010). These include: (i) Providing a safe test scenario for the trainee. (ii) Protecting patients from injury caused by novices undertaking risky procedures (iii) Chance for group training of technical behavioural skills (iii) Ability to practice rare complications, and incidents which are valuable to learn (iv) Scenarios can be deliberately chosen rather than patients arriving randomly in-vivo (v) The ability to pause a training session for discussions, providing real-time evaluation (vi) A chance to retry failed tasks, or to use another method (vii) Opportunity to try different tools without risk to patients (Merién et al., 2010).

VR training as a supplement can improve physical skill of minimally invasive surgery trainees, decreasing the time taken for suturing plus improving precision (Nagendran et al., 2013). Studies have demonstrated the efficiency, repeatability, and realism of training on simulators (Merién et al., 2010).

4.1.3. Costs of Medical VR Training.

For medical training the cost effectiveness of VR simulators is another consideration. High fidelity simulators range from about five thousand dollars for laparoscopic simulators up to a quarter of a million dollars for technically advanced erudite simulators for anaesthesia (Issenberg et al., 1999). The costs of conventional training for a surgical trainee with conventional training for 4 years is around fifty thousand dollars (Bridges et al., 1999). Also residents require additional time to complete procedures. Conventionally surgical trainees are apprentices who learn from expert surgeon supervision, which is takes a lot of time, is expensive and is not always equally effective (Nagendran et al., 2013).

4.1.4. Remote Surgical, Laparoscopic and Endoscopic Training.

Within surgical simulation, a core aspect of research on automation focusses on transferring automation of simulated surgical procedures including remote haptic training in MOOCs into automation of actual procedures. Developments on automation within VR therefore feed directly into improving robotic-assisted surgery including the da Vinci surgical robot. The line is becoming blurred between simulated and remote haptic interaction environments. Therefore a trainee may not be able to tell whether their haptic data-glove is interacting with a remote artefact or a simulated artefact. Due to this similarity, the assistive robotic surgery designed to operate on simulators could be more easily transferred into real operating scenarios. Future applications to improve robotic-assisted surgery and remote surgery will require improved force and tactile feedback (Okamura, 2009).

Laparoscopic surgery is now more widespread. Laparoscopy reduces incision size, but increases procedural difficulty, leading to increased training requirement. Recently VR simulators for laparoscopy have been developed to aid training (Gallagher et al. 2002).

Endoscopic surgery has also been a good example of haptic VR training, enabling trainees to learn the unique hand-eye coordination and perform surgery such as detaching the gall bladder and performing electro-surgery (Ahn et al., 2014).

4.1.5. EU Funding for Medical VR Training.

Medical VR training has been a focus of several recently funded European Commission projects: (EU Mindwalker project[h]) funded €2.75M until 2013, proposes a mind controlled VR training environment for walking. The (EU VRSurgicalSimulation project[i]), a fellowship funded €87K until 2010 focussed on simulators combining engineering with medical knowledge. The (EU Enorasi project[j]), funded €1.5M until 2004 focussed on VR for training visually impaired.

4.2. Industrial and Commercial VR

Significant recent research on industrial virtual training has focused on spatial manipulation for assembly tasks (Brough et al., 2007). The primary focus of recent research within VR for assembly tasks focusses on developing robust and real-time collision detection, assembly path planning and physics modelling. Case studies outline several applications of virtual assembly in industry (Jayaram et al., 2007).

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[h] http://www. mindwalker-project.eu
[i] http://cordis.europa.eu/project/rcn/92531_en.html
[j] http://cordis.europa.eu/project/rcn/92531_en.html

Adaptive VR Simulators have also been developed for training pilots on aircraft controls (Ko et al., 2015), (Olivari et al., 2014) and driving vehicles (Yamashita, 2014).

Adaptive VR interfaces have been implemented within e-commerce websites to make a customer's online shopping seem realistic, fun and attractive (Chittaro et al., 2000). Adaptation is an important feature when applying a one to one commerce strategy. The ADVIRT system demonstrated an adaptive VR environment using customer models, adapting virtual shop features: (i) presenting varying merchandise on the shelves (ii) customised banners and audio advertising, (iii) directions for the shoppers, (iv) the arrangement and visual effects (Chittaro et al., 2000).

Adaptive VR training systems have been developed for military personnel (Khan et al., 2013), (Popovic et al., 2009). Military adaptive VR systems optimise and customise the training experience to the physical ability of individual trainees (Popovic et al., 2009). The automated system configuration is beneficial as it relieves the therapist of repetitively monitoring and manipulating the system manually.

In-vehicle assistive technology (IVAT) is an example of predictive or assistive technology already being used in automobile technology, such as the audio feedback produced to indicate distance when parking. In some cases a vehicle's computer can ultimately stop the vehicle in order to avoid accidents.

Driving simulators which use prediction are widely popular on all major games consoles. A variety of haptic joysticks and seating pads are available. Haptic steering wheels such as INRETS-FAROS or 'The Haptic Wheel' are especially for driving. Recently eye-tracking has been combined with haptics for prediction and analysis. Eye-tracking whilst driving can be used to analyse the driver's attention hotspots, predict driver fatigue to assist the driver's safety and eye-tracking can autonomously draw comparison between novice and expert drivers (Horng et al., 2004).

4.2.1. Assessment within AR and VR training for commercial and industrial

There are many commercial and industrial applications for HMDs and AR (Furht, 2011) including adaptive military training (Fig. 7) (Khan et al., 2013), automotive safety, public exhibition and entertainment, environmental planning and psychology.

The generic virtual training (GVT) system provides assessment and training for a range of industrial applications (Gerbaud et al., 2008). Validation of GVT on more than fifty operational scenarios shows that it helps learning to quickly pick up new industry processes.

A VR system was developed for training and assessment of conveyor belt safety for personnel working in the mining industry (Lucas et al., 2007). The VR safety training contains instructional-based and task-based VR modules. The assessment evaluates the user's understanding and ability to resolve situations during completion of a planned list of virtual tasks (Lucas et al., 2007).

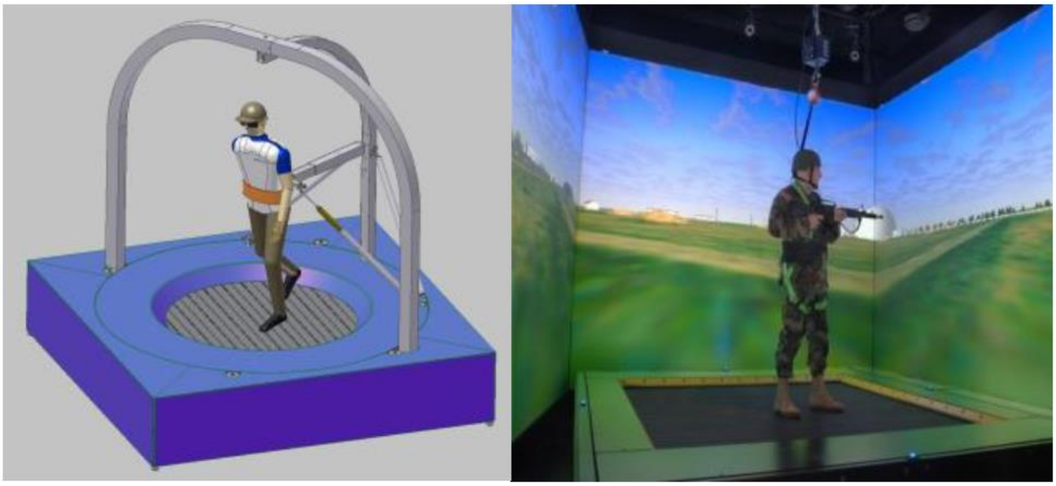

Fig. 7. Adaptive military VR training, re-produced with permission (Khan et al., 2013).

4.2.2. EU Funding for Industrial and Commercial VR Training.

Industrial VR training has been a focus of several recently funded European Commission projects: (EU Vision project[k]) funded €1.4M until 2011, proposes immersive interface technologies for aircraft related VR. The (EU VIRTHUALIS project[l]) funded €9M until 2013, proposes to combine human knowledge with VR simulation to improve safety during production of chemicals. The (EU Vega project[m]) funded €900K until 2008, proposes the use of VR in product design and robotics, with VR simulation including manufacturing and recycling.

4.3. Collaborative and Remote VR Training and MOOCs

MOOCs can benefit from adaptation to generate customised learning material for each user. MOOCs are designed for unlimited participation via the web, for example when coordinated at universities. They allow subjects to be taught using conventional methods and other media, including video, as well as providing a community for discussions of topics. This also includes online discussions and scored tests for distributed groups.

MOOCs often make use of autonomous agents for virtual training. Several hundred MOOCs have been created, with an enrollment rate of around 40,000 students per course (Jordan, 2014). Some of the largest extended MOOCs (xMOOCs) are featured on platforms like Coursera or edX. Development costs for xMOOCs vary from $38,000 to $325,000 (Hollands & Tirthali, 2014). The largest costs relate to generating the video content (Lewin, 2013).

Multimodal wired data-glove devices combined with VR remote environments can provide virtual presence, tele-presence, tele-existence or a virtual artefact (VA).

4.3.1. Collaborative and Teamwork VR Training.

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[k] http://cordis.europa.eu/project/rcn/88551_en.html
[l] http://cordis.europa.eu/project/rcn/75752_en.html
[m] http://cordis.europa.eu/project/rcn/75559_en.html

Collaborative e-learning or remote tele-learning is an emerging need of the information age. In future significant benefits are expected from distance learning, tele-learning, and online distributed and collaborative virtual training (Bouras et al., 2000). Virtual training environments should be knowledgeable, dispersed for group tele-learning. This uses intelligent agents as Pedagogical assistants to assist trainees and enable smooth completion of the training scenarios (Bouras et al., 2000).

Collaborative virtual training is useful in medical procedures where a surgery requires two people, for example one person may hold the gall bladder whilst another cuts the connective tissues (Gunn et al., 2005).

The ways in which team size effect simulation training needs to be determined by further exploration, according to a review of group training for nurses (Cant et al., 2010). Also a universal method of outcome measurement should be developed. “The training content, team membership stability, and team size moderate the effectiveness of team training interventions” (Salas et al., 2008).

Teamwork training in simulation results in improved “knowledge, practical skills, communication, and team performance” (Merién et al., 2010) shown by a review covering 97 articles for obstetrics. Teams of medical staff need to practice collaboration and communications to improve efficiency and effectiveness. Therefore introduction of multidisciplinary team and group training on simulators aims to prevent adverse outcomes (Merién et al., 2010). Team training is a viable approach which can enhance the outcome of the team and helps to improve effectiveness, teamwork, performance and cognitive outcomes (Salas et al., 2008). Teams are ubiquitous, representing important groups to achieve goals (Marks, 2006).

4.3.2. Remote patient monitoring.

Clinicians are now increasingly able to remotely monitor patient health, give consultations and advice and prescribe medicine. Teki is a tool which uses an Xbox games console for remote monitoring patients by collecting data from medical devices, enabling staff to monitor patients remotely (Teki, 2013).

4.3.3. Adaptation within MOOCs (a-MOOCs)

Adaptive MOOCs (a-MOOCs) are recently becoming more popular, using a combination of adaptive learning and MOOCs. Hidden Markov Models (HMMs) are useful in a-MOOCs to predict student retention (Balakrishnan, 2013). HMMs which apply single discrete-valued observation variable are preferable, as opposed to multiple stream or continuous HMMs, due to their ease of training and well-established tool support. Ergodic, as opposed to linear HMMs enable independence of the features although several transformations of data are required.

Features of a-MOOCs can be customised to match particular subpopulations of trainees, identified using scalable, informative classification methods (Kizilcec et al, 2013). Learner sub-populations and their longitudinal engagement trajectories can be classified from their patterns of interaction with e-content. Classifier mechanisms and fine grained analytics form a framework for comparison of learner engagement, consistently identifying prototypical trajectories of engagement, across learner demographics, forum participation, e-content access, assessment and experience.

An adaptive MOOC for calculus, named (MOOCulus [n]) was developed in 2015 at Ohio State University by Professor Jim Fowler. The a-MOOC contains a fine-tuned adaptive learning engine which adapts each student's e-content to match their measured understanding level. The adaptation engine determines whether to serve extremely difficult or easy exercises, considering participation data, time taken and colour coded progress bar, providing data-driven feedback on classroom effectiveness.

4.3.4. EU Funding for Collaborative VR.

[n] https://mooculus.osu.edu/

Funding allocations for current and recent research gives a good indication of the activity within specific areas. There are recently funded projects within collaborative VR and MOOCs which indicate a good level of research activity. The European Commission project: (EU LEAP project[o]) funded €223K until 2016 focusses on virtual archaeology encouraging collaboration between trans-disciplinary departments, experts and audiences.

4.4. Serious VR Games for Training

Serious games can enable learning through playing and encourage the repeating of tasks to reinforce learning. Rewards are built-in, including goals, narratives, rules, multisensory cues and interactivity which aim to inspire users to keep playing. A review has summarised the ways in which video games can be designed for education (Dondlinger, 2007).

Recent motion-sensing controllers for games including Nintendo Wii Balance Board[p], Sony Playstation Move[q], and Microsoft Kinect[r] have revolutionised the ability of video games for rehabilitation use (Pirovano et al., 2012). These devices can capture movements or gestures from the user in the real world with a hands-free approach and convey them inside the game.

4.4.1. Adaptation within VR Serious Games.

Successful modern video games must be adaptive to requirements, anticipations, and inclinations of the player. Yet from a software engineering perspective, current adaptation in games is ad hoc, "lacking rigor, structure, and reusability, with custom solutions for each game. There is a critical need for software frameworks, patterns, libraries, and tools to enable adaptive systems for games" (Choudhury et al., 2013).

Frequent adaptation within the setup of levels plus adaptation to user's activities often enhance adaptive VR games. "Adapting to a player's current skills make gaming experience more engaging" (Pirovano et al., 2012).

Adaptive serious game training engenders "communication opportunities for players to learn about their strengths and weaknesses, receive real-time in-game performance feedback, share diverse solutions and strategies during, between and after game play in order to update or adapt player understanding" (Raybourn, 2007).

Serious learning games have also incorporated aspects of customised player experience, by exploring various aspects of adaptive content. Customising the content can provide the player with a more suitable level of challenge. There is some overlap between games and medical training simulation, both can benefit from adaptive user-centred content, and elements of adaptive games could be re-used to apply to medical simulators providing adaptive user-centred content (Fig. 9).

Computational intelligence within games is of growing importance to various scientific disciplines. Research on this field "is very active and vibrant, but it is still at an early developmental stage" (Lara-Cabrera et al., 2014).

4.4.2. EU Funding for Serious Games VR.

The European Commission recently funded Serious Games especially since the recent increase in augmented reality: (EU AUGGMED project[s]) funded €5.5M until 2018 focusses on automation within

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[o] http://cordis.europa.eu/project/rcn/187945_en.html
[p] https://en.wikipedia.org/wiki/Wii_Balance_Board
[q] https://www.playstation.com/en-us/explore/accessories/playstation-move/
[r] https://dev.windows.com/en-us/kinect
[s] http://cordis.europa.eu/project/rcn/194875_en.html

collaborative virtual and mixed reality serious games. The (EU Safe and sound drive project[t]) funded €98K until 2016 is designing a serious game for cars to help increase driver skills and lower fuel consumption.

4.5. Rehabilitation VR

VR games are well suited for rehabilitation because: (i) they engage the users (Borghese et al., 2013). (ii) Games can contain intelligent systems to adapt to the user's progress (Pirovano et al., 2012). (iii) Rehabilitation games "can be used at the patient's home" (Pirovano et al., 2012).

Analysis of SWOT (Strengths, Weaknesses, Opportunities, and Threats) identifies that VR has significant positive impact on rehabilitation (Rizzo et al., 2005).

Computational intelligence and adaptation can both provide significant benefits to the patient when applied within rehabilitation VR, and can supplement the therapist's input with a virtual therapist as shown in Fig. 8.

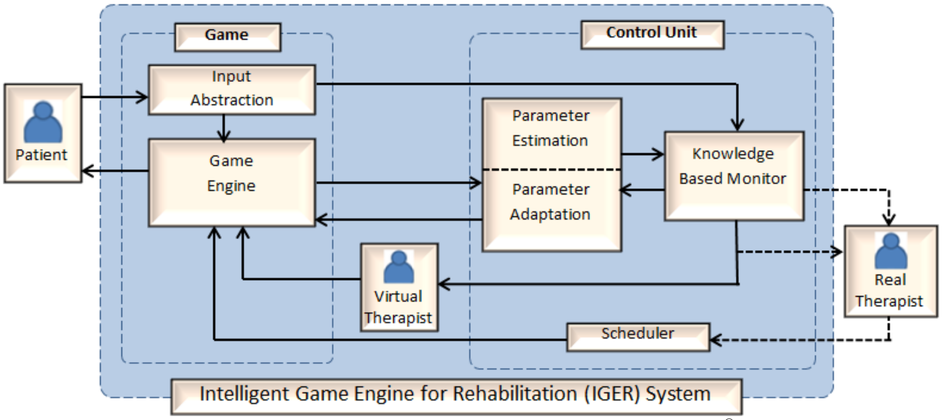

Fig. 8. Intelligent adaptation with Bayesian networks and fuzzy systems based on Nintendo Kinect® motion sensing controllers for VR rehabilitation games (IGER) (Borghese et al., 2013).

4.5.1. Adaptation within Rehabilitation VR Games.

Virtual reality rehabilitation systems are incorporating adaptation to meet the changing requirements of patients and therapists (Kallmann et al., 2015). Adaptation to each patient's functional status is a key requirement in rehabilitation games such as Intelligent Game Engine for Rehabilitation (IGER). "IGER is based on computational intelligence, monitoring is implemented in fuzzy systems, containing rules defined for the exercises by clinicians," (Borghese et al., 2013) as shown in Fig. 8. Adaptation of exercise difficulty level achieved using a Bayesian framework from observations of the trainee achievements.

Adapting to the patient capability and status is important within rehabilitation VR and especially serious games. Games for virtual rehabilitation can adapt to the player's "pathology and rehabilitation aims" (Ijsselsteijn et al., 2007).

Adaptation and customisation has proven useful within VR training to enhance training for motor skills of prosthetic systems (Davoodi and Loeb, 2012).

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[t] http://cordis.europa.eu/project/rcn/195412_en.html

An adaptive rehabilitation game was developed for stroke patients using "physics-enriched virtual environments. Factors such as gravity can be scaled to adapt to individual patient's abilities and in-game performance" (Ma et al., 2007).

The VividGroup's Gesture Xtreme projected VR neurological rehabilitation system adapts scenarios in terms of "type, speed, location and direction of all stimuli" (Kizony et al., 2003). Adaptable VR systems offer advantages as a rehabilitation tool.

4.5.2. Wireless Kinect and Wiimote sensors for Rehabilitation Games.

During rehabilitation, "monitoring the patient's motion is mandatory to avoid maladaptation" (Borghese et al., 2013). VR games can assist this by using a variety or combination of wireless motion tracking devices to enhance patient motion analysis. Feedback on motion analysis, "performance and progression of the exercises can be provided" (Borghese et al., 2013).

A wireless multisensory intelligent rehabilitation environment has been proposed based on gerontechnology in which technology is used to support the aspirations of the elderly. A Kinect sensor is used to detect the movement of the patient and Wiimote actuator is used to provide haptic feedback (Oliver et al., 2014).The Kinect sensor has recently been very useful for several rehabilitation systems by detecting the user's posture (Chang et al., 2011), (Lange et al., 2011), (Freitas et al., 2012), (Chang et al., 2012), (Pirovano et al., 2013), (Fuentes et al., 2013), (Toyra, 2013) (Oliver et al., 2014). A study (Davaasambuu et al., 2012) tested Microsoft Kinect for replacing conventional rehabilitation therapy. Microsoft Kinect sensor measured reliability of gesture recognition in between 88.0% - 92.2% and was rated as more fun and easier to use than the conventional rehabilitation system. Evaluation studies of Kinect for rehabilitation have been conducted (Freitas et al., 2012) showing that improvements can be achieved by (i) improved, cleaner user interface, (ii) improved feedback given to the patient following a wrong movement and (iii) clearer instructions to the patient. This shows the importance of keeping the patient central when planning and designing VR-based rehabilitation environments.

The adaptive IGER Rehabilitation system can attach to several wireless tracking devices "through an input abstraction layer, including Nintendo® (Kyoto, Japan) Wii™ Balance Board™, the Microsoft® (Redmond, WA) Kinect, the Falcon from Novint Technologies (Albuquerque, NM), or the Tyromotion (Graz, Austria) Timo® plate balance board" (Borghese et al., 2013).

4.5.3. Non-adaptable and Manually adaptable Rehabilitation Games.

Non-adaptable computer-assisted integrated game solutions for rehabilitation have been proposed (Mainetti et al., 2013), (Boghese et al., 2012), (Jack et al., 2011), (Cameirao et al., 2010), (Burke et al., 2009a + b). These rehabilitation games can provide intuitive guidance through rehabilitation exercises. Most rehabilitation applications are limited as they rarely include any adaptation (Pirovano et al., 2012).

VirtualRehab (Virtualware Group) is a set of 9 rehabilitation games and exercises aimed at treating many disabilities. The physiotherapist can manually customise the treatment for each patient by choosing which games to assign. The game uses playful components to induce the user to feel more comfortable during treatment (VirtualRehab, 2013).

4.5.4. Rehabilitation VR training.

For rehabilitation, VR is becoming an "integral part of cognitive ability assessment. VR has potential to assist rehabilitation techniques and training strategies addressing impairments, disabilities, dysfunction, memory impairments, spatial ability impairments, attention deficits, and unilateral visual neglect and to offset handicaps associated with brain damage" (Rose et al., 2005). VR has been useful for rehabilitation after stroke (Langhorne et al., 2009).

A review of VR rehabilitation for intellectual disabilities shows that VR offers potential for "intervention and assessment. VR conveys concepts without use of language or by symbol systems" (Standen et al., 2005) making it ideal for mental disabilities. Benefits of VR fit into three groups: "promoting skills for independent living, enhancing cognitive performance, improving social skills; grocery shopping, preparing food, orientation, road safety, and work skills." (Standen et al., 2005).

4.5.5. Disabilities VR training

Manually adaptive virtual reality systems have been used to train severely disabled people to use electric wheelchairs (Rossol et al., 2011). Each patient is different, so generic training is not suitable. Adapting the training for each patient proves an effective supplement for rehabilitation (Rossol et al., 2011). Important challenges remain including: (1) high setup costs (2) continual manual adjustments to adapt the simulation to the patient improvement over time. Bayesian networks provide an effective solution for automating adaptive training (Rossol et al., 2011).

For autism and people suffering autistic spectrum disorders (ASD) and Asperger syndrome (AS), VR "offers a new and exciting perspective on social skills training" (Parsons 2002) to practice role-play situations and repeat tasks.

4.5.6 EU Funded Rehabilitation VR Games

Rehabilitation VR games have been the focus of several recently funded European Commission projects: (EU Rewire project[u]) funded €3.5M until 2015 proposes an adaptive personalised VR health system. (EU CogWatch project[v]) funded €3.6M until 2015 is a personalised home rehabilitation system using intelligent objects and tools to re-train patients on activities of daily life, providing persistent multimodal feedback (EU Script project[w]) funded €3.3M until 2015 uses a tele-robotic glove with VR games to rehabilitate hands of stroke patients, and predict impact on health, and recovery costs. (EU iStoppFalls project[x]) funded €3.3M until 2015 applies ICT home-based sensors, telemedicine and video games to assess fall risk in elder citizens.

4.6. Transfer of technology between VR topic areas.

The topics of VR simulators overlap since there are technologies that can be re-used between several or all VR topics. The centre of Fig. 9 shows the core technologies covered in section 3, some of which are hardware and some are software. The outside arms of the Venn diagram Fig. 9 show the topic areas of VR-based training which the core technologies can be applied to.

Due to the recent boom in the games industry there has been boosted technological advancement in input devices for games including HMDs, haptic devices, and wireless motion tracking such as Kinect. These developed technologies also have been useful in other VR topics. For example Kinect is used in various medical VR training. In this way, transfer of technology between the topics is useful to re-use content or techniques.

Traditional medical training is done with mentoring in which one mentor may have up to five students. However with MOOCs the size of classes can be several hundred thousand and this puts strain on the traditional feedback methods, and one to one feedback is no longer feasible. New approaches to assessment have been developed to meet these challenges in MOOCS and these may be useful in other topics such as medical, industrial or commercial VR training. One approach to automate the interaction and assistance of large tutor groups are autonomous agents. An agent named Steve was developed to "help students learn to perform physical procedural tasks" (Rickel and Johnson, 1999). Intelligent agents were additionally developed as Pedagogical assistants (Bouras et al., 2000).

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[u] http://www.rewire-project.eu
[v] http://www.cogwatch.eu
[w] http://www.scriptproject.eu
[x] http://www.istoppfalls.eu

In the topic of VR-based rehabilitation, the primary objective is assessment of the patient’s motion. Therefore assessment has become well developed in rehabilitation and could be used for assessment in serious games or other VR medical training.

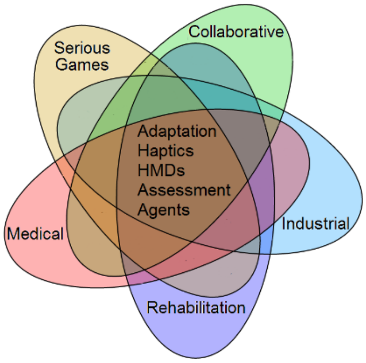

Fig. 9. There are overlapping areas between topics of VR training and core technologies can apply to all.

5. Future technology in VR Training

The majority of VR research focuses on medical training, with other industries receiving less attention. There is currently increased research activity within rehabilitation games.

No common framework or method has yet been defined to customize learning content within VR training for individual trainees. Data mining of user scores and other measured performance data provide a possible solution. A database capturing results for all trainees could be data-mined by an algorithm to formulate a customized training plan for each trainee.

One of the future visions of physiology driven adaptive VR “is endowing the computers with automated emotion recognition capabilities, in order to facilitate a range of applications in which the computers respond appropriately to the emotions of their users” (Popovic et al., 2009).

Adaptive systems can already contribute towards predictive and assistive technology for controlling flights on autopilot. Assistive driving vehicle technology is becoming more widespread, including Google self-driving cars[y]. In addition to vehicles, automation could ultimately be the direction of other haptic tasks, such as surgery. The ultimate goal for fully autonomous systems is for the system to perform visio-haptic tasks without the requirement for a human operator to be present.

Several current technical challenges for haptic robot-assisted surgery are discussed in (Okamura, 2009). There are already situations where machine precision can outperform human judgement. Haptic simulations can provide a platform for development and testing of autonomous technologies, which can transfer into real-world haptic control. Real world adaptive haptic control systems could be applied to surgery or autonomous vehicles. These may contain assistive technologies to enhance the operator’s precision or skill, or predictive systems, enabling the system to decide when to intervene to avoid predicted accidents.

Digital human modelling is increasing used within VR. The IOWA Interactive Digital-Human Virtual Environment (Yang et al., 2004) popularised the use of digital human modelling within VR by use of kinematic modelling of human. This is a special application with digital humans in virtual reality and can be used to enhance various applications in current and future research.

[y] http://www.google.com/selfdrivingcar

6. Summary of Technologies used within Virtual Training Simulators

This section presents a series of tables comparing the findings from this overview. Table 3 gives examples of VR simulators demonstrating which VR training topics have used which VR technologies. There are examples for all possible combinations, showing that generally all core VR technologies can be useful for all VR topic areas.

Table 4 shows examples of multimodal technologies within VR simulators, where two technologies have been combined together, including examples of existing VR simulators. The table shows that many technologies have been combined together with other technologies in the existing simulators. There are currently a lack of examples where autonomous agents have been combined with other technologies, but agents have been combined with adaptive content.

Table 5 shows examples of adaptation within each core VR technology. The table demonstrates that all of the core technologies make use of adaptation.

Table 6 shows examples of adaptation within the VR Topic areas. All five of the VR topic areas have made use of adaptation and examples are presented.

Table 3. The use of each core technology in each VR topic area (*Italic* entries are adaptive)

VR Topics	Haptic Devices	HMDs	Adaptive Content	Assessment	Autonomous Agents
Medical VR	Mist VR; VHB	(Erat et al., 2013) (Fichtinger et al., 2005) (Ghanbarzadeh et al., 2014)	*Bayesian adaptive VR Wheelchair (Rossol et al., 2011)*	(Vaughan et al., 2015a)	(Carbonell et al., 2007) (Larsson et al., 1998)
Serious Games	Nintendo® Wii™ Balance Board™, Sony® Playstation™ Move.	Oculus Rift. (Furht, 2011)	*(Pirovano et al., 2012) (Raybourn, 2007). (Lara-Cabrera et al., 2014).*	*(Raybourn, 2007).*	(Buditjahjanto 2011)
Industrial and Commercial VR	*(Ko et al., 2015), (Olivari et al., 2014). (Yamashita, 2014).*	(Furht, 2011)	*ADVIRT (Chittaro et al., 2000). (Popovic et al., 2009)*	(Lucas et al., 2007). (Gerbaud et al., 2008)	(Cabri et al., 2011) (Collins et al., 2006) (He et al., 2003)
Collaborative VR & MOOCs	(Gunn et al., 2005) (Okamura, 2009).	Tele-presence. (Furht, 2011)	a-MOOCs. (Kizilcec et al, 2013). MOOCulus.	MOOCulus. (Kizilcec et al, 2013)	(Bouras et al., 2000)
Rehabilitation VR Games	(Oliver et al., 2014), (Chang et al., 2011), (Lange et al., 2011	(Rushton et al., 1996) (Myers and Bierig, 2000)	*(Pirovano et al., 2012), (Ijsselsteijn et al., 2007), (Ma. 2007), (Kizony et al.,2003)*	(EU iStoppFalls) (Myers and Bierig, 2000). (Rushton et al., 1996).	*(Kallmann et al., 2015)*

Table 4. Multimodal core VR technologies which have been combined together in VR.

Core VR Technologies	Autonomous Agents	Assessment and scoring	Adaptive Content	HMDs

Haptic Devices	(Vaughan et al., 2014)	Expert guidance	(Ko et al., 2015), (Olivari et al., 2014). (Yamashita, 2014).	Visio-haptic simulators
HMDs	(Sharma et al., 2014)	(Myers and Bierig, 2000) (Rushton et al., 1996).	(Chen et al, 2014)	
Adaptive Content	(Rickel and Johnson, 1999). (Stenudd, 2010).	(Raybourn, 2007).		
Assessment and scoring	(Rickel and Johnson, 1999)			

Table 5. Adaptation within the core VR technologies.

Core VR Technologies	Examples of Adaptation and Automation within VR technologies
Haptic Devices	Aircraft controls (Ko et al., 2015), (Olivari et al., 2014). Vehicle driving (Yamashita, 2014).
HMDs	HMD automated calibration using neural networks (Chen et al, 2014).
Assessment and scoring	Strengths, weaknesses, real-time in-game feedback (Raybourn, 2007).
Autonomous Agents	Agents with machine learning to improve over time (Stenudd, 2010). Agent Steve sets adaptive goals (Rickel and Johnson, 1999).

Table 6. Adaptation within the VR topic areas.

VR Topic Area	Adaptation and Automation within VR topics
Medical VR	Bayesian adaptive VR Wheelchair (Rossol et al., 2011)
Serious Games	Adaptation of game levels and player activity (Pirovano et al., 2012) Adaptive Serious Games (Raybourn, 2007). Computational intelligence within games (Lara-Cabrera et al., 2014).
Industrial and Commercial VR	Adaptive e-commerce websites ADVIRT (Chittaro et al., 2000). Adaptive Training for Military (Khan et al., 2013), (Popovic et al., 2009).
Collaborative & Remote VR & MOOCs	a-MOOCs. (Kizilcec et al, 2013). MOOCulus.
Rehabilitation VR Games	(Pirovano et al., 2012), (Ijsselsteijn et al., 2007), (Ma et al., 2007), (Kizony et al., 2003), IGER (Pirovano et al., 2013), (Kallmann et al., 2015)

7. Conclusions

This current overview has summarised the state of the art virtual reality training systems using self-adaptive technology. Automation, machine learning and data driven features play an important role in providing trainee-specific individual adaptive training content. Data forms a critical input to enable adaptation within virtual training systems. Trainee assessment data can enable customised training scenarios and automated difficulty levels to match individual expertise. Data from audio-visual sensors can capture human behaviours for programming realistic autonomous agents. Expert knowledge and haptic measurements can be used to improve the accuracy of haptic feedback and guidance.

Adaptation has been applied to all five core technologies within VR training: adaptive technology, haptic devices, head-mounted displays, assessment, and autonomous agents.

With haptic devices, adaptive elements of a user's physical skills can be measured in terms of the angle, force or rotation of the haptic instruments. This is useful for adapting to the trainee's skill and expert haptic guidance.

Head-mounted displays (HMD) have used automated calibration using neural networks (Chen, 2014).

Assessment can be automated to provide an unsupervised and unbiased scoring mechanism enabling content and VR scenarios to adapt to suit the trainee's experience.

Autonomous agents can adapt to the way the trainee's interact with virtual content. Autonomous agents provide many benefits for virtual training courses, such as: being viable alternative to lecturers (Li et al., 2015), collaborating and sharing knowledge between each other, replacing missing team members (Lopez et al., 2014), acting as pedagogical assistants, interacting with trainees to facilitate training (Bouras et al., 2000).

There are five core topics within VR training: medical, industrial & commercial, collaborative & MOOCs, serious games and rehabilitation.

In medical VR training adaptation is used in Bayesian network systems proving effective for automated adaptive virtual training (Rossol et al., 2011).

For industrial & commercial VR training, adaptive technology has been used for military training (Khan et al., 2013), (Popovic et al., 2009), pilot training (Ko et al., 2015), (Olivari et al., 2014) and vehicle driver training (Yamashita, 2014).

Adaptive collaborative VR & MOOCs can predict trainee learning (Balakrishnan, 2013), identify trainee sub-populations and to adapt trainee content (Kizilcec et al, 2013). Adaptation is used to spot patterns of interaction with content.

Serious game levels can adapt to player activity. Games can be adaptive to "the needs, expectations, and preferences of the player. There is a need for software frameworks, patterns, libraries, and tools to enable adaptive systems for games" (Choudhury et al., 2013).

In rehabilitation VR training the exercise difficulties can adapt using a Bayesian framework to an individual patient's abilities and functional status which helps avoid maladaptation (Pirovano et al., 2013). Input data can be collected from an abstraction layer using wireless tracking or audio-visual devices, to adapt with the patient's improvement over time.

There is not yet a common infrastructure making the automated technologies more combined and portable. Currently many implementations of adaptation within VR are independently developed. A key step forwards would be to produce a portable framework for VR automation combining adaptation with each core technology within VR training. This would enhance the benefits of automation and make adaptation more accessible for a variety of VR training. A future priority is to develop a method of customising VR learning to follow recent changes in training infrastructure. The most important aspects of such a system would be: (i) Customised level of complexity, being not too easy or hard for the individual. (ii) Focus on areas of strength or weakness for each individual's most urgent learning requirements. (iii) Haptic feedback and guidance should enable a trainee to correct and fine tune their physical aspects including force, angles and rotation of the tools. (iv) Assessment and scoring is necessary to feedback to the user, but also to feed the AI algorithms for adaptive content.

Adaptation can help to enable a change away from textbook learning to the use of smart media and on-screen learning. This new change provides opportunity for customised adaptive learning to individualise e-content. As adaptation technology emerges there are considerations such as benchmark checks which should be performed to assess the capability of this new platform to out-perform the conventional approaches. The current new generation of trainees will demonstrate the benefits of the current smart training revolution.

There is increasing use of adaptation within VR training. Adaptation has benefits within several VR technologies. Adaptive VR training can achieve significant impact and improve training in the five key topic areas.

Acknowledgements

The authors would like to acknowledge Bournemouth University for funding this research. They would also like to acknowledge the help of various anonymous reviewers who provided feedback which helped strengthen the research. We acknowledge the editors of International Journal of Soft Computing and Software Engineering (JSCSE) for permission to re-produce Fig. 7.

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