Implementation of virtual reality in technical education – an innovative way out

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ABSTRACT

Application of virtual reality (VR) in technical education sector is getting more popular day by day. It is considered as an active and more practical way to teach technical students to achieve enhanced practical knowledge and experience. VR supports the practical experience of technical learning through mimicking the real world activities with the help from computer simulation. It is operated through the specific technique and software tools which are integrated together to support such innovative learning process. This study extensively investigates the possibility to teach engineering students with the help of VR. The inherent benefits of VR in technical education are elaborated within the scope of this research study. In addition, a case example is demonstrated with the objective to learn insight of this concept. Overall outcomes from the case example are presented along with the various works done by researchers and practitioners are reviewed and highlighted as well.

***Keywords*:** Virtual reality, 3D visualization, technical education, innovation, case study

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Application of virtual reality (VR) in technical education sector is getting more popular day by day. It is considered as an active and more practical way to teach technical students to achieve enhanced practical knowledge and experience. VR supports the practical experience of technical learning through mimicking the real world activities with the help from computer simulation. It is operated through the specific technique and software tools which are integrated together to support such innovative learning process. This study extensively investigates the possibility to teach engineering students with the help of VR. The inherent benefits of VR in technical education are elaborated within the scope of this research study. In addition, a case example is demonstrated with the objective to learn insight of this concept. Overall outcomes from the case example are presented along with the various works done by researchers and practitioners are reviewed and highlighted as well.

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1. Introduction

The research on virtual reality in conceptual learning is growing rapidly due to its accompanied benefits. The increased maturity of VR technologies triggers to expand research from the military and visualization realm to other domains such as education, art and psychology. Although VR is extensively used in military and games industries but its application in education is relatively young. In general, VR can have strong motivational power through immersion environment (Gallagher and Cates, 2004; Corbetta et al., 2015). There are several educational VR projects have been created, which offer VR-based learning applications. From research study, it is shown that most of the VR projects involve the creativity, exploration and collaboration between both remote and collocated learners.

The development in the field of VR is adequate so far and can be considered in innovative applications such as education, training and research in higher education (Abulrub et al., 2011). The application of VR in education offers both benefits and challenges. The main challenge to apply VR in education sector is associated to its relatively higher costs, which often cannot afford by the educational institutions. However, recent advancement in VR technology has made it feasible into future teaching strategies. In spite of the cost issue, the benefits of VR in education and learning arena are huge (Gorski et al., 2011).

Due to increasing demand for innovation in technical education and recent advancement in 3D visualization technology, wide range of engineering teaching and training can be supported by the VR environment (Grajewski et al., 2015). The VR technology can be used as a supportive methodology and tool for the advancement of technical education. It significantly enhance the learning experience through realism and interactivity. In order to apply VR approach in engineering education care should be taken due to the descriptive and complex nature in engineering problems. The application of VR can bring new style in technical education through teaching technique, especially the use of laboratory demonstrations. Such demonstration is directly used to enhance the student's practical knowledge. Based on the above circumstances this research study summarizes following two motivating research questions:

(1) What are the associated benefits to apply VR in technical education?
(2) How VR can be used to support innovation in practical knowledge and learning for engineering students?

The rest of the paper is organized as follows: Section 2 demonstrates the relevant literature of VR applicable to education and other sectors, while Section 3 highlights the research methodology adopted for this research study. Applications of VR in technical education sector are elaborated in Section 4. Essential technologies and tools to create VR working environment is outlined in Section 5. An elaborative case example is demonstrated in Section 6 to explain the learning process through VR. Generic discussions and limitations of VR in highlighted in Section 7, whereas Section 8 concluded the research outcomes with future research directions.

2. Literature review

2.1 Virtual reality: today's dilemma

Today's advancement of information and communication technology (ICT) has been transforming manufacturing industry in myriad ways. Many of the relevant ICT developments are not made directly for the sake of manufacturing, so industrial researchers and professionals may not be fully aware of the adaptation of the new technologies. One critical area of ICT is VR that already applied commonly in various areas such as entertainment, design and manufacturing and simulation training (Gorski et al., 2016). In reality, VR already has different applications within manufacturing sector (Pandilov et al., 2015). VR applications for the manufacturing sectors are applied extensively and its implications for the sector are significant. It is therefore, necessary for the manufacturing researchers and professionals to best prepare themselves to face the challenges and take benefits that VR offers.

The concept of virtual reality (VR) can be defined as a computer-generated environment, where the viewer can experience a different reality. This environment is often considered as an extension to 3D computer graphics, which offers a three-dimensional view. The integration of 3D design and manufacturing provides manufacturing firms a means of envision, refine and develop a product or process with substantial time and cost savings (Gorski et al., 2011). The VR environment offers a person a sense of reality. This technology allows the designers to virtually manufacturing and maintenance works (Grajewski et al., 2015). This technology mainly uses a combination of headsets, controllers and optics. Often the headsets are integrated with headphone to upgrade the user's experience with the aid of 3D audio system.

2.2 Applications of virtual reality in various domains

In literature, substantial research has been conducted on the application of VR in different domains starting from military sector to industrial and service sectors. It is widely used in military training (Zyda, 2005), automotive and aerospace design (De Sa and Zachmann, 1999), medical training (Gallagher and Cates, 2004; Corbetta et al., 2015; de Boer et al., 2017), and entertainment (Stapleton et al., 2002; Tromp, 2017; Jung et al., 2018). Automotive giant Jaguar Land Rover used 3D digital prototyping to make decisions in the early stages of design (Attridge et al., 2007). VR offers suitable environment for any kind of design reviews that supports to reduce product development lead-time and costs with improved quality of new products and services (De Sa and Zachmann, 1999).

The VR technology has made new opportunity for delivering education and training in immersive ways. Past challenges from technology and cost have impeded advancement of VR in education and training. Industries as well as educational institutes are now moving fast to adopt VR as a training tool (Grajewski et al., 2015). The efficient immersive environment created by VR applications has been very successful in developing positive learning outcomes in a variety of fields (Jayaram et al., 1997; Gavish et al., 2015; Fiard et al., 2014; Gibson and O'Rawe, 2018). The VR provides on-site training and learning in a safe and controlled environment (Berg and Vance, 2017. It supports virtual learning in impossible locations through the access to cost-prohibitive equipment (Jerald, 2017).

VR technique presents a new way to engage technical students in the learning process. It creates technologically minded students with higher levels of engagement in learning process than to traditional teaching methods (Dalgarno and Lee, 2010; Lawrie, 2017). Such explorative environment allows the users to experiment with an environment that in real world could be dangerous (Bricken, 1991; Blazy, 2015; Lawrie, 2017). Due to nonreality of the resources in this environment allows the users to conduct experiment which might be dangerous in the real world. Through this sound and safe learning environment, the users would be able to get experience and feeling as if real with minimum cost and hassles (Fowler, 2015; Hubbard et al., 2017). In addition, the costs associated with mistakes or errors in VR environment are lower in comparison to the potential physical costs in the real world.

The VR technology as training tool can be designed to have limited or no physical prototypes (Grajewski et al., 2015; Jerald, 2017). It is often possible to use a hybrid system, where both physical and virtual interfaces are combined, known as physical mock-ups of interfaces. VR training tools can be used with minimum supervision (Dalgarno and Lee, 2010; Hubbard et al., 2017). A user can be fully engaged in the virtual environment where he\she can acts as he\she do in the real world (Craig et al., 2009; Berg and Vance, 2017). A summary of few applications of VR in various domains are highlighted in Table 1. From Table 1, it is noticed that

Table 1. Applications of VR in various domains.

Serial number	*VR application areas*	*Contributed authors*
1	Product design and development	Craig et al. (2009); Gorski et al. (2011); Grajewski et al. (2015); Pandilov et al. (2015); Gorski et al. (2016); Berg and Vance (2017)
2	Medical science	Aggarwal et al. (2007); Bellani et al. (2011); Kandalaft et al. (2013); Fiard et al. (2014); Corbetta et al. (2015); Laver et al. (2015); de Boer et al. (2017)
3	Education	Bricken (1991); Dalgarno and Lee (2010); Blazy (2015); Fowler (2015); Nikolic et al. (2015); Hubbard et al. (2017); Lawrie (2017); Spolaor and Benitti, 2017; Bower et al. (2017)
4	Games and entertainment	Guttentag (2010); Tromp (2017); Jung et al. (2018); Moorhouse et al. (2018)
5	Manufacturing industry	Jayaram et al. (1997); Gavish et al. (2015); Grabowski and Jankowski (2015);
6	Business and entrepreneurship	Tromp (2017); Bonetti et al. (2018); Gibson and O'Rawe (2018)
7	Tourism industry	Huang et al. (2016); Castro et al. (2017); Jung and tom Dieck (2017); Jung et al. (2017); Gibson and O'Rawe (2018);

3. Research methodology

This research study was conducted both theoretical and practical way. In the theoretical part, extensive literatures were revised in different domains where VR is applied successfully. However, special focus was given to the application of VR in technical education sector. From the survey it is noticed that few works have been done on technical education although application of VR in other sectors are increasing rapidly due to its inherent benefits.

In the practical part of this research, an elaborative case study was conducted in order to authenticate the use of VR technology and tool to educate engineering students. From the case example, it is noticed that extensive practical knowledge and training can be offered to the engineering students through VR. A simple welding operation in a sheet metal piece was demonstrated exclusively where the welding operation was conducted virtually. This technique offers the virtual training to the operator, which contributes to learning process with minimum investment.

4. Application of VR in technical education

The VR is increasingly applying in educational industry due to its inherent benefits. It is highly usable in engineering education due to its 3D visualization technologies (Manuel, 2017). It is therefore required for the educational institutions to make plan for its implementation in both infrastructure development and policymaking (Al-Zoubi et al., 2007; Lamb et al., 2010). In educational industry there needs distinctive skills that support innovative teaching and learning to compete in today's competitive world. To stay in competition, engineering students needs to prepare themselves to apply theoretical knowledge to real industrial problems. In addition, students also need to acquire skills like creativity and innovation, communication, team-based learning, project/problem-based learning, problem solving and business skills.

The explosive development of ICT and increasing interest motivates educational institutions to adopt sophisticated technological means, innovative environments and equipment (Dehn et al., 2018). Hence, today institutions are considering the use of interactive installations, simulation environments and virtual reality (Hubbard et al., 2017). Such specific interest to educational institutions in the use of VR displays and computer generated interactive experiences allows students to travel through space and time without stepping out of the real industrial establishments (Nikolic et al., 2015). In recent days, research on VR in education sector has focused on the potential of immersive displays, which makes the learning experience easier and more realistic (Padilha et al., 2018).

The 3D interactive VR visualization system prepares engineering students for practical training of real industrial environments (Lawrie, 2017). This emerging technology offers students with real-life examples mimics by creating virtual environments. Such training through virtual learning process enables students to contribute industrial problem solving skills, which consequently supports to improve the productivity of world-leading businesses. It also supports inquiry-based educational activities and interactive hands on experience to the students (Spolaor and Benitti, 2017). Interactive and immersive 3D visualization tool can create a pipeline for collaboration and cooperation with education industry to prepare engineering students with the necessary skills and expertise required for business (Potkonjak et al., 2016).

The VR technology helps engineering graduate with advanced knowledge that can be used in innovation activities to add value, reduce product time-to-market and make cost savings. It also supports engineering student to defining product requirements well ahead before new product introduction to the market that meet customer expectations (Bower et al., 2017). Today's industrial sectors need engineering graduate with distinctive knowledge and skills to develop innovative solutions that ultimately contributes to improve profit, reduce cost, improve quality and product excellence. It is hoped that integrating VR technologies and tools in technical education would offer better and innovative knowledge and training of future engineers to fulfill industry needs.

5. Creation of VR operational environment: essential technologies and tools

In order to create three-dimensional VR operational environment there needs to integrate several technologies and tools. Most of the techniques and tools are compatible with each other, which is necessary to develop a seamless VR working environment. This VR environment combines both hardware and software, which allow the designer to be immersed in the environment. The VR operational environment can be defined as a system that is implemented to address a specific technical scenario representative of actual issues facing an industrial facility. This system provides the operational engineer with high quality, stereoscopic graphics by using a head-mounted display.

Required movement of the head-mounted display is monitored and controlled by electromagnetic positioning devices that automatically allow the user to look around. Different movements of the head are monitored and tracked by the hands of the user by additional positing devices. These movements are used to create and manipulate operational scenarios in the virtual environment. In order to monitor the movement of the fingers and wrist, the user uses an instrumented glove. The operational personnel use such virtual working environment to select optimal operational sequencing, evaluate required tolerances, create operational plans and results visualization.

In order to design and develop VR environment it is essential to integrate multiple domains and synchronize with related technologies. Such integration makes the VR application more effective and efficient in nature. The VR environment allows the technician to pursue operational activities virtually. This virtual operational system supports relevant training instruction with a reliable and easy way. This environment provides real-time simulation and interaction with a virtual 3D world.

The application of VR environment requires technologies such as Unreal Engine 4, HTC Vive, HTC Vive Headset, HTC Vive Controllers, HTC Vive Base station, Vive Tracker, etc., (Vive, 2017). The Unreal Engine 4 is used as the main software to create the virtual environment. This environment is required to simulate virtual industrial operations. The HTC Vive is a virtual reality headset that is designed and developed by HTC and Valve Corporation. It offers 'room scale' tracking technology that supports the user to move in 3D virtual space. The HTC Vive consists of one VR headset, two controllers and lighthouse base stations (Fig. 1), which are required parts to create and operate VR environment.

Fig. 1. HTC Vive bundle essential parts.

The HTC Vive headset tracks the head position through a gyro sensor, an accelerometer and a laser position sensor. It uses two screens, one per eye and includes a front-facing camera that allows the user to observe their surroundings. The HTC Vive controllers are considered as the hands of VR that let the user wirelessly interact with virtual objects, making a more immersive experience for the user. It consists of a track pad, grip buttons and a dual-stage trigger as seen in Fig. 2. (Ben, 2017). The Vive tracker functions similar to Vive controllers and the Vive headset by collecting information from the infrared emitted by base stations. By using the tracker, the user will have an immersive VR experience (VRHeads, 2017).

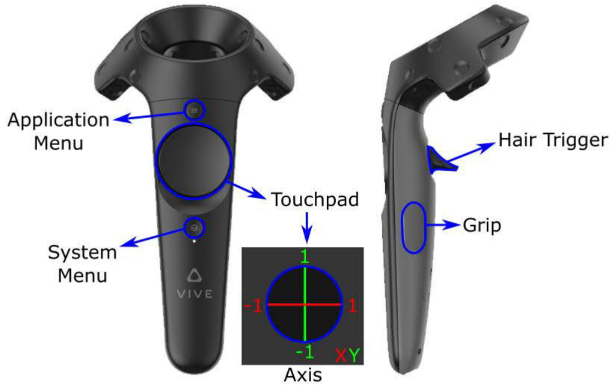

Fig. 2. HTC Vive controller buttons.

The HTC Vive base stations, also known as lighthouse-tracking system consists of two black boxes that create a 360-degree virtual space up to 15 x 15 foot radius (Vive, 2017). This lighthouse tracking system tracks every moment with sub-millimeter precision with the aid of 37 sensors in the headset (Ben, 2017). Fig. 3 displays a HTC Vive base stations set up position.

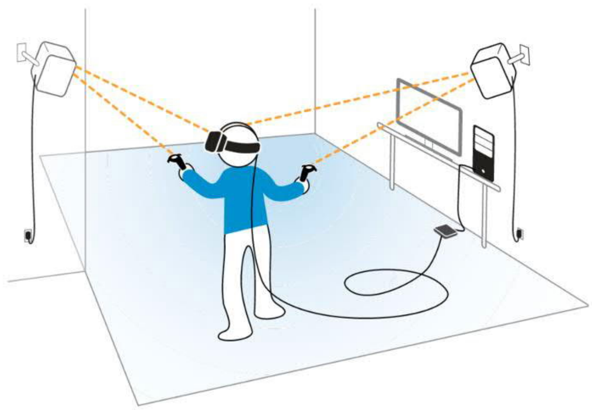
Fig. 3. HTC Vive base stations set up position.

6. Learning through VR: a case example

In order to demonstrate the application of VR in technical education, an approach was taken where necessary spot welding on a sheet metal was done through robotic arm. This VR work environment was developed with ABB Robotstudio software (http://new.abb.com/products/robotics/robotstudio). In order to conduct such experimental set up required robot is selected along with spot welding tool attached at the robot's arm. The initial set up for spot welding using robot is displayed in Fig. 5. From Fig. 5, it is seen that welding tool is positioned on the job sheet for necessary welding operation. Different types of welding tools can be attached on the robot arm depending on the welding requirement.

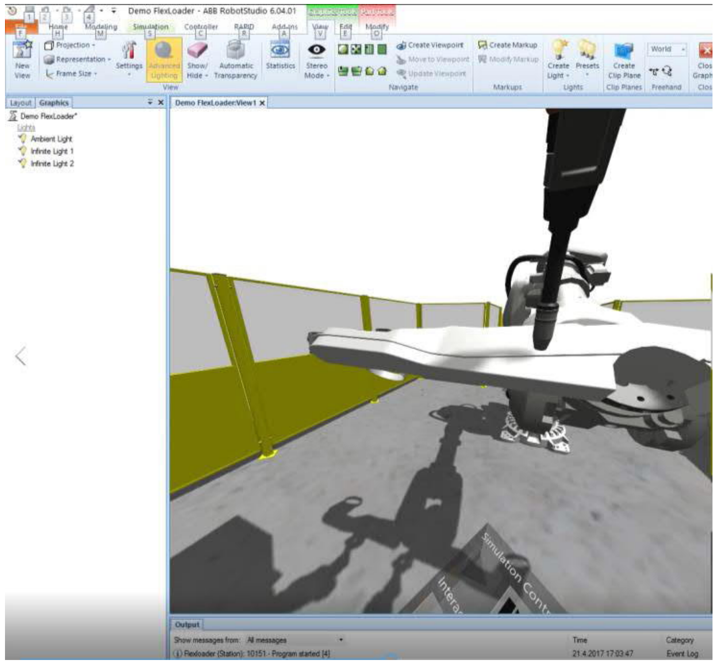

Fig. 5. Display of spot welding through VR environment.

The VR welding environment was created through Visual Components software (http://www.visualcomponents.com/). Required 3D working environment is created by this software application successfully. In order to move to the necessary position to perform the welding operation, the operator uses teleporting. Such teleporting enables the operator for longer movements by walking. The operator uses VR glasses to visualize the movement of robot arm. The glasses cover the all the essential views of visions. Two HTC VIVE lighthouses (https://en.wikipedia.org/wiki/HTC_Vive) are used to view and control the robot arm for necessary welding operations. The user uses front-facing camera as attached to the headset to monitor surroundings areas.

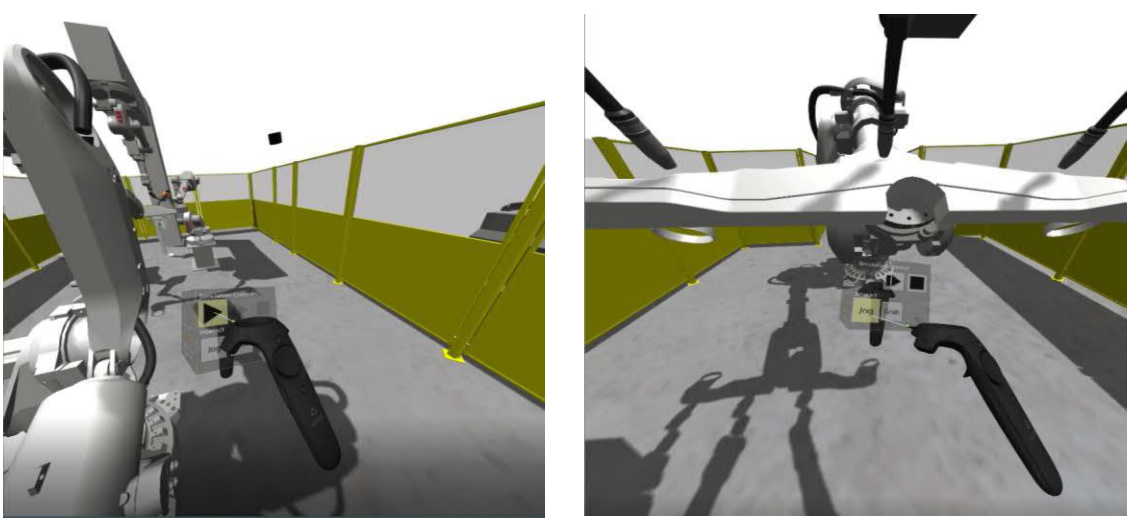

Fig. 6. Display of HTC VIVE controller as used to spot welding through VR environment.

Fig. 6 displays the HTC VIVE controller that controls the operator's movements to weld specific area on the sheet metal. Through such teleporting device, the operator enables to position him/herself accordingly. The HTC VIVE controller have several commands such as jog, play, edit, delete, etc. These commands are required for controlling the robot's arm, which are necessary to perform specific operation efficiently.

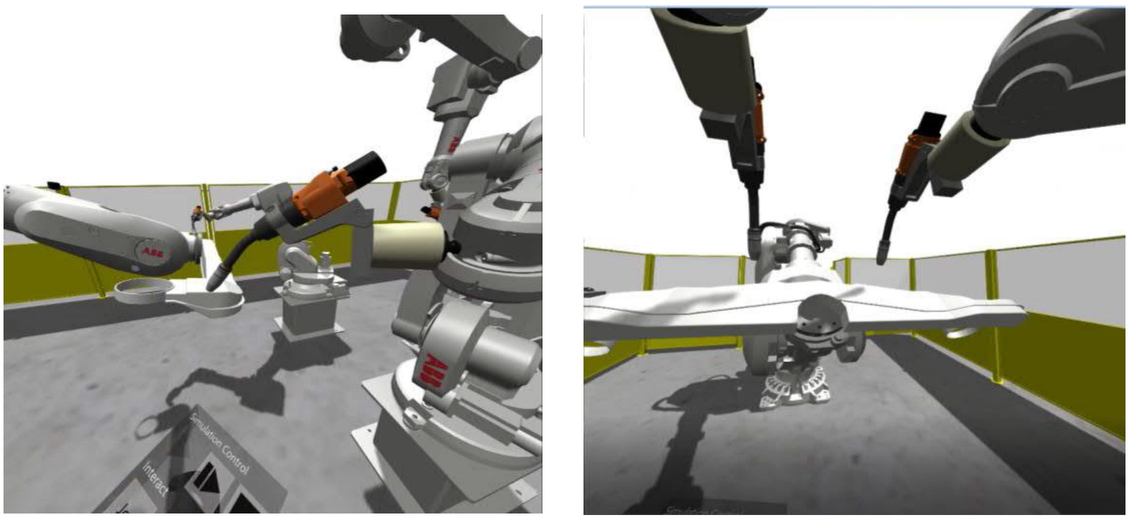

Fig. 7. Display of two-robotic arms used for spot welding through VR environment.

The teleporting is also used for operating multiple welding tools as attached the robots arms. Fig. 7 displays the two welding torches as attached to the two robot arms. Through simulation control exact positioning of the spot welding is dine, which is displayed in Fig. 8 accordingly.

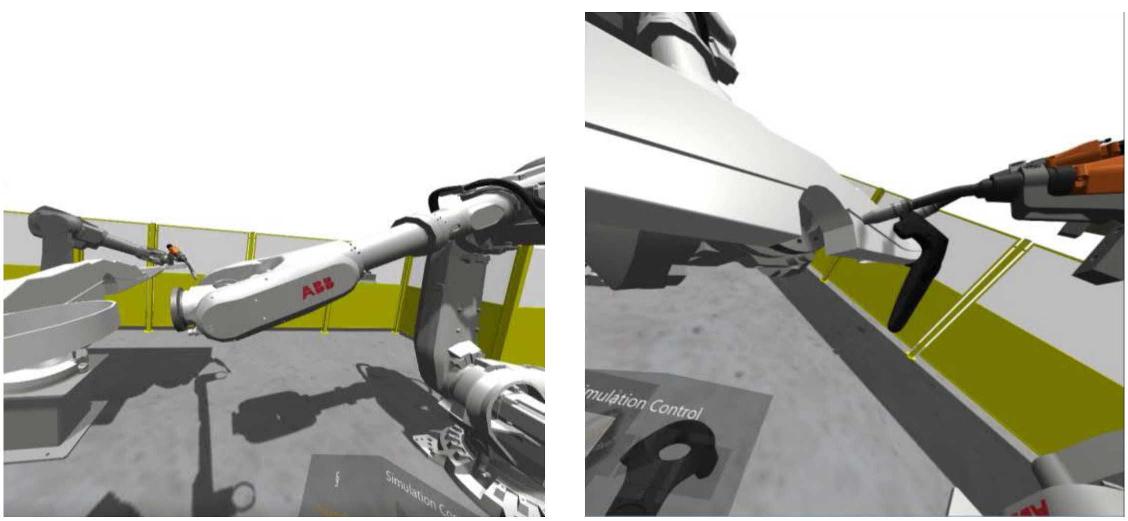

Fig. 8. Display of spot welding through VR environment.

The required twisting of the welding tool is controlled by the command 'jog', which grab the robot arm and twist it according to the operational needs. Fig. 8 displays the twisting position of the robot arm as necessary to spot different locations of the sheet metal. Other available commands are also used to spot welding for better performance.

7. Discussions and limitations of VR in engineering education

VR is helpful to teach technical students through an effective way of emphasizing things through visualizations, which is not possible by the traditional teaching methods. It offers amazing experiences that may never be possible in the real world of learning. It motivates students to learn with the use of this technology while they sit and watch something instead of reading it. In today's classroom environment it is often difficult to create a productive engagement within the class. With the help of VR technology such challenging environment can be disappeared, where students will feel tempted to talk about their experiences within their virtual world. It also removes the language barrier which often appears a big problem to education.

Teaching through VR environment helps students to engage more as compared to traditional school based learning. This technology is especially helpful for the technical or engineering students to learn technical works virtually in an easy, cost effective and safer way. There are many learning benefits offered by the virtual world. In this immersive environment, the teachers have to plan carefully to their courses in order to engage students in virtual world without much hassle. The course contents need to be tailored according to virtual world as well. One of the major appealing features of VR to engineering students is the ability to take students in the areas that are otherwise inaccessible, such as the inside of a nuclear reactor, or boiler to inspect and work safely in a virtual environment.

The implementation of VR in technical education is not an easy job. It has several limitations. The main limitation is to the cost related to this technology. This technology requires educator training, operation and maintenance, proper usability, etc., making the educational use of VR difficult to incorporate in dwindling institutions budgets. Other limitation associated with the complexity of VR technologies, which often prohibits it, flexibility of use. If the technology goes wrong, students learning activity is hampered substantially until and unless it is fixed. In addition, there is a possibility that students getting addicted to their virtual world instead of working enthusiastically in the real world experiments. In VR environment, the users are restricted to move unlike in the real world, that often restricts the user for comfortable use of the technology.

8. Conclusions and future works

Learning through virtual worlds causes positive attitude in learners. It offers to the users cognitive and most out of learning that can engage users in authentic and challenging tasks. Today's increasing number of technical or engineering students making more challenges to the institutions to offer practical learning environments. Due to the laggings of practical laboratories those are often overcrowded worsening the teaching quality and reducing the teacher's dedication to every student. Engineering students demands for the high technological profile in order to fit them to compete with hi-tech job markets. There are several cases where outdated teaching practices create barriers for some students to use interactive technological events. In such situation, VR applications allow that students can perform several technical activities by their own which saves teachers time on intrinsic explanations. In virtual world, the teachers need to follow some guidelines to guide learners in exploring, teaching and producing knowledge.

The objectives of this research were to present the associated benefits and applications of VR in technical education. In addition to highlights the associated benefits the objectives were also focused to find a way out how VR can be applied successfully to teach technical students in more practical way. Due to accompanied limitations, it is often challenging to teach technical students practically, which are critical to prepare better for future technicians or engineers. The implementation of immersive learning process through VR technology can also be used for distance learning that can opens up significant contributions in the field of pedagogy and the design of effective learning experiences. The continued progress of VR through computer graphics and virtual world's technologies can provide the opportunity to learning through virtual laboratories which can eventually reduce the necessity of real world laboratories.

One case example is illustrated within the scope of this research study with the objective to demonstrate the practical application of VR in technical education. This case study can be employed to produce creative learning and training engineering material and environments. The institutions to meet the expectation of today's up-to-date student generation in terms of research and learning processes can adopt the VR technology. The acceptance rate of VR technology among technical students is quite high which allow them to successfully perform any learning process. This tool offers a dual effect by allowing the teachers to improve technical guidance at the training sessions within practical classes and to offer students an attractive and motivational tool during learning process.

Although the application of VR is very much useful for learning process through sharing technical knowledge safely but it is quite expensive. Due to higher cost often limits its implementations to the higher educational institutions. However, many educational institutions have already implemented this impressive technology for research and educational purposes due to its inherent benefits. As the technology is developing day by day, it is expected that it will be more affordable in the sooner future. In such situation, it is expected that more institutions will implement the required hardware and software to adopt VR for the future technical education scenarios and to guide better learning environment. In future research, effort will be taken to look for the possibilities to implement a VR technology for technical education sector with reasonable cost and reduced complexity. More examples of VR in technical education will also be harnessed for the betterment of engineering students.

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