DESIGN AND DEVELOPMENT OF VIRTUAL ENGINEERING LAB

Timothy Hatchard, Mohammad-Al-Amin, Zeina Rihawi, Alaa Alsebae , Freeha Azmat

University of Warwick

ABSTRACT

Virtual reality (VR) is a method of immersing a person into a virtual environment by using a headset with a screen and lenses to simulate a 3D experience. This project aims to test the effect of using VR in engineering laboratories to improve the quality of teaching in Science, technology, engineering, maths (STEM) subjects. In this study, VR technology was used to design and develop an engineering laboratory. This would illustrate the fundamental concepts taught in the real laboratory to the Mechanical engineers. The VR lab was created using Unity, a game development software. The VR lab was tested with students from the School of Engineering and Warwick Manufacturing Group at the University of Warwick. Students participating in the study were given two identical assessments, one before and one after being in the VR lab experience. The difference in student learning depicted by assessment scores was compared to the result attained from the students exposed to the traditional learning style. A final questionnaire was given to each participant, allowing them to share their opinion and show their emotions towards their learning method. It was observed that students attained better assessment scores when exposed to the VR lab experience. In addition, positive comments were received from students, stating they found VR to be an engaging platform for learning.

KEYWORDS

Active learning; e-learning; innovative ideas to teach engineering using virtual reality; digital learning; Standards: 8.

INTRODUCTION

Education and training, especially in STEM subjects, are areas in which continuous improvements and evolution of methods are required to advance at the same rate as the complexity of the subjects taught. "*The problems include a lack of practical skills in modern engineering training, the lack of relevance for industry of the science being taught… As these problems have not been properly addressed and the demand for well-trained engineers has increased steadily, the situation in today's smart society is even more challenging"* (Michael E. Auer, Kwang-Sun Kim, 2016). Engineering education requires a more practical focus in order to properly train modern engineers for the complex systems that exist in the world. Currently, this experience only exists in the form of experimental laboratories; a student may only receive a few of these opportunities in each university year. Limitations of these current laboratories include a high cost, time, space requirements, and maintenance.

It is suggested that laboratories may lack a clear learning objective and as such could be less useful for the education of students (Lyle D. Feisel, Albert J. Rosa, 2013). The limitations previously mentioned stopping these laboratories from being as effective as they might be. With better training before the laboratory, students may proceed with a better understanding of the desired outcomes before starting the lab; allowing them to take full advantage of the laboratory experience. Currently, these labs are prefaced with a briefing sheet and occasionally a briefing lecture to allow students to prepare themselves in advance of the lab. It is often seen that students barely read the briefing sheet, if at all, and go into the lab with no clear idea of what they are trying to achieve.

This project proposes to test the effect and acceptability of a new method of training: VR. This technology would allow students to take part in a simulated version of the laboratory without as many of the costs and hazards involved with the real version. Further benefits include the ability to go back to the laboratory in their own time to practise or remember the experience to further their understanding. The predicted benefit is that students will understand more about the laboratory before going into it with the VR training compared to the traditional briefing sheet. To prove this hypothesis, an experimental method was set up, along with a VR of the chosen lab, to test student's understanding before and after their training. Students would participate in either the VR or traditional training and measurement of their learning performance is taken, along with their acceptance of the completed method.

The main objective of this project is to research if there exists a benefit of using VR to train students compared to current briefing methods. This research could then act, with existing research, as a basis for the inclusion of VR and similar technologies in education and training within STEM subjects. Thus, it helps improve the quality of comprehension and perhaps allowing even more complex systems to be researched and understood.

The paper has been arranged as follows where Section 1 deals with the literature review, Section 2 explains the experimental method followed by results and discussion in Section 3. Finally, conclusions are presented in Section 4 which is followed by future work in Section 5.

LITERATURE REVIEW

VR uses a small screen and lenses inside a head-mounted display (HMD) to make the user feel as if they are inside a digital three-dimensional world. This virtual world is generated by a game development software package. For this study Unity was used to develop the virtual environment. VRTK (Virtual Reality Toolkit) is a free toolkit used with Unity to easily setup the VR environment. Blender and Substance Painter were used to model and texture the objects in the lab. VR could be used in several different engineering education applications: Lectures, workshops, classes, and labs. It could have the benefit of allowing students to become more engaged in the activity by fully immersing them. Some of these scenarios could potentially work better than others. For example, lectures in VR would differ very little from the traditional lecture providing few benefits. Although, labs in VR would be very similar but offer the benefit of safety and reduced equipment cost, while allowing additional virtual elements to enhance the experience.

E-learning is the use of electronic and online resources for education. Serious games are games designed to educate, rather than to entertain. A meta-analysis of serious games can be found in the Psycnet article (Wouters, Pieter, van Nimwegen, Christof, van Oostendorp, Herre, van der Spek, Erik D., 2013). This showed a significant positive effect in learning and retention; the serious games were just as motivating as traditional methods. E-learners continued to learn more when the games were replaced with other e-learning sources, such as team games, new instructions, and multiple sessions. Therefore, it is suggested that e-learning provides a consistent improvement. E-learning is likely more effective because students can learn in their own time and preferred environment. Since there is no classroom to attend, students can learn when it suits them. Therefore, they are less likely to be sleepy or stressed, which has been proven to negatively affect learning (Dean W. Beebe Ph.D., Douglas Rose M.D., Raouf Amin M.D., 2010). Furthermore, students may participate more as there will be no fear of failure, which is shown to encourage students not to participate to avoid embarrassment (De Castella, K., Byrne, D., & Covington, M., 2013). Since failure is the way humans learn and improve, encouraging students not to fear occasional failure to improve overall will increase the learning resource's benefits (Johannes Bauer, Christan Harteis, 2012). This will also encourage students to explore options, regardless of if they think they are right or wrong. Furthermore, repetition of the material can assist learning (Kang, 2016); students can repeat e-learning material whenever they want but are unable to repeat a class. Without needing to travel, students can learn in a personalised and comfortable environment. Furthermore, e-learning activities involve 2D animations, games, and interactions to attempt to improve attention and learning quality. VR serves to do the same, just in 3D, though similar its benefits include a much greater sense of immersion and attention. The user has a sense of being there, much improving the quality of learning, as shown by the IEEE's study (C.E. Hughes, C.B. Stapleton, D.E. Hughes, E.M. Smith, 2005).

In the Investigation and Application of Virtual Reality as an Education Tool, (John T. Bell, H. Scott Fogler, 1995) the effectiveness of several different teaching methods is discussed. It uses Bloom's Taxonomy, shown in figure 1, which describes a hierarchy of learning objectives which represent how well a person has learned something. This starts from memorising, then understanding, and so on up to evaluating and creating. Furthermore, the article states that alongside Bloom's Taxonomy, that identifying the best methods for teaching is necessary. The paper states that traditional teaching methods typically only provide the first 3 levels of Bloom's taxonomy; If the teaching resource provides an experience where students leave with a comparatively higher level and include all the learning styles, then it will certainly be effective in educational use. To achieve this, each item in Bloom's Taxonomy and the learning styles should be closely analysed and understood. This way, programs developed for education can adhere to these methods to ensure the application is effective in teaching, more so than just an interesting new technology.

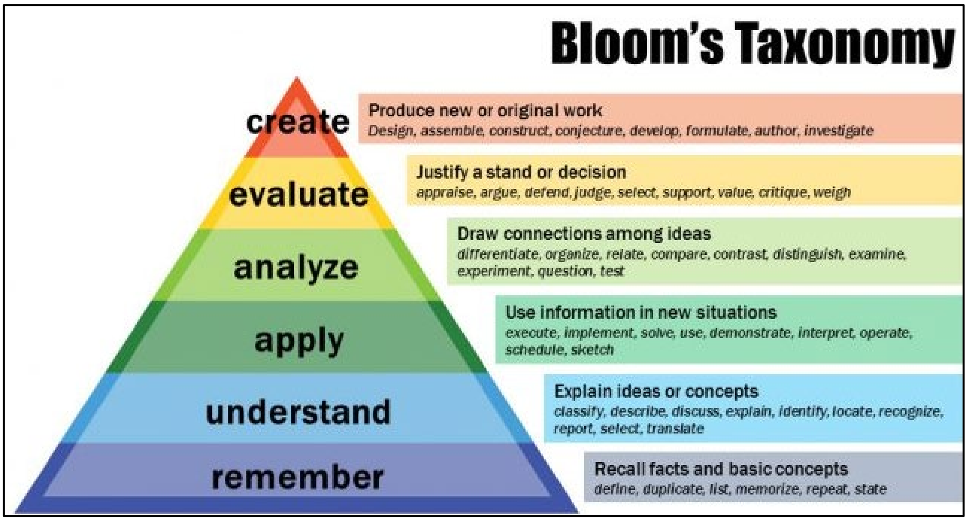

Figure 1: Bloom's Taxonomy Graphic (Armstrong, 2006)

Sensory, visual, and inductive learning styles are known to be preferred by engineering students (John T. Bell, H. Scott Fogler, 1995). As such, they should be focussed on most when considering the development of an educational VR tool. To summarise there are many different aspects to cover if VR in engineering education is going to be useful. It has already been proved that the technology could help, but how to do so has hardly been covered. So, to make VR in education as effective as possible, teaching and learning methods need to be considered. Bloom's taxonomy is useful in considering the different levels of learning and how they can be achieved. The learning styles should also be considered for VR applications to work for students and teachers effectively. Making a VR application which not only demonstrates, but helps students understand, analyse, and create while focussing on a sensory, visual and inductive experience would be the most effective teaching resource to come from the technology.

In the PNAS article (Scott Freeman, Sarah L. Eddy, Miles McDonough, Michelle K. Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Pat Wenderoth, 2014), a meta-analysis of active learning was carried out and a 6% increase in exam grade was seen over 225 different studies. Intuitively, active learning should be more effective for STEM subjects. The subjects are involved, complex, and full of design and construct. To learn this, one needs to take part, this is active learning. Learning styles are less to do with personal preference and more to do with the subject. The American statistician’s journal entry (Kvam, 2000) examined the immediate and long-term effects of active learning instead of traditional. The experiment showed an increase of retention with average and low scores. This is preferred, as the longer-term learning benefits are much more desirable.

VR provides new possibilities not previously accessible by traditional teaching methods. It allows the incorporation of muscle memory, interactions, and three-dimensional visuals. It has already proven to be effective for motor rehabilitation and with further use and development of the technology it could be worth the investment. In the Biomed Central article (Heidi, 2004), VR was shown to be as effective as the real-world equivalent. Therefore, VR clearly has a positive effect on people in training and rehabilitation scenarios, and it is worth testing if this effect could extend to education and learning. The NCBI article (Neal E. Seymour, MD, Anthony G. Gallagher, PhD, Sanziana A. Roman, MD, Michael K. O’Brien, MD, Vipin K. Bansal, MD, Dana K. Andersen, MD, and Richard M. Satava, MD, 2002) showed VR to give a significant performance increase and a large failure reduction rate while training for an operating room environment. Those taking part showed a 29% faster performance and were nine times less likely to fail. Training is very similar to classroom education in some cases, so these benefits could be transferable to education.

From the above, a benefit is clearly predictable and therefore the tests are justified. The initial costs included in adopting VR are steep, though the maintenance costs are considerably lower compared to traditional training methods. For example, to train students to take apart an engine, in VR a few headsets and PC's would be required costing a few thousand pounds per set-up. To do this in the real world, the equipment, upkeep, and repair costs are also very high. Students health must be considered, such as motion sickness, soreness, repetitive strain injury (RSI), etc. A combination of both traditional and VR methods would be the most beneficial as VR or traditional methods alone are not effective enough. Traditional and e-learning methods are currently combined in this manner, which proves to be effective. This is called blended learning and is more effective than traditional or purely e-learning methods (Means, B., Toyama, Y., Murphy, R., & Bakia, M., 2013)

EXPERIMENTAL METHOD

The chosen lab for this project was a second-year engineering laboratory: pipe flow. A virtual version of this laboratory was developed using the game creation software Unity. A free collection of code was used called Virtual Reality Toolkit (VRTK) which contains the code required to make VR interactions within the application. Blender was used to model the apparatus used in the lab and a free trial of Substance Painter was used to apply colours and textures to these models to make them look realistic. The interactions between the student using the application and the virtual apparatus were programmed with calculations to simulate the expected results from the inputs given. A tutorial was then coded to guide the user through the method for taking the required measurements, as well as stopping them from making mistakes which could be potentially damaging to them or the equipment in the real experiment. Once the virtual experiment is completed, information on the theory of the lab is then displayed along with diagrams to help their understanding. The final laboratory can be seen in figure 2.

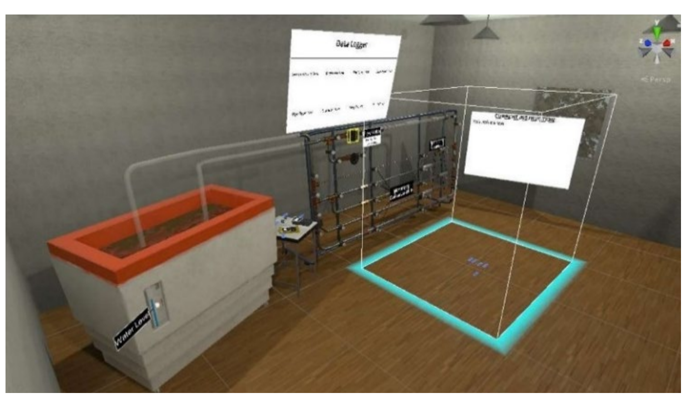

Figure 2: The virtual laboratory designed in Unity for the students to complete.

To understand the effectiveness of the virtual lab, a measurement of the students learning performance and acceptability of the learning method is required. To measure learning performance, an identical test was given to students before and after partaking in their learning method, these questions were chosen to accurately account for theory and practical knowledge that should be acquired before taking part in the laboratory. It was anticipated that students should be able to answer very few of the questions before, but much more after their learning session. After the students have completed the training and knowledge tests, a UTAUT (Unified Theory of Acceptance and Usage of Technology) questionnaire was given with questions tailored towards the acceptance of the technology. Due to the wording of the questions, they also applied to the briefing sheet and so a direct comparison of acceptance and emotion can be drawn between the two methods.

During the experiment itself, the student is given roughly 15 minutes to complete their training. This is so students have an equal amount of time to understand the laboratory as if they were to take part in it later. Both tests were run in a quiet room, one at a time, to prevent distractions. For the briefing sheet, students would read and take notes as required, but when answering the knowledge tests the briefing sheet and any notes made were removed. For the VR lab, students followed the instructions and a supervisor was present to help them with controls and understanding of the technology itself, but not the content. This is because VR is still a new technology and it is unlikely for participants to be familiar with the equipment and so aid is given to help make it a fairer comparison.

RESULTS AND DISCUSSION

The following tables show the test scores before and after the VR and briefing sheet trials and the questionnaire answers. Measurement of improvement can be taken by comparing the difference in student's correct answers before and after. Each test is out of a total of 23 marks. Table 1 shows the marks given for the 10 questions in each of the participant knowledge tests, followed by a total and an average; participant numbers are given at the top.

Learning Performance

Table 1: Comparison of knowledge test scores for VR and the briefing sheet

	Question Number	Average for VR Participants	Average for Briefing Sheet Participants
Pre-Test	**1**	0.3	0.3
	2	0.1	0.1
	3	0.0	0.1
	4	0.7	0.6
	5	0.0	0.0
	6	1.2	1.1
	7	0.1	0.2
	8	0.5	0.5
	9	1.1	1.1
	10	0.4	0.6
	Total	**4.4**	**4.6**
Post-Test	**1**	1.6	0.4
	2	0.6	0.1
	3	0.8	0.6
	4	0.7	0.6
	5	0.7	0.0
	6	1.8	1.3
	7	0.5	0.5
	8	2.4	1.5
	9	2.6	1.8
	10	6.6	2.3
	Total	**18.3**	**9.1**
Difference	**1**	1.3	0.1
	2	0.5	0.0
	3	0.8	0.5
	4	0.0	0.0

	5	0.7	0.0
	6	0.6	0.2
	7	0.4	0.3
	8	1.9	1.0
	9	1.5	0.7
	10	6.2	1.7
	Total	**13.9**	**4.5**

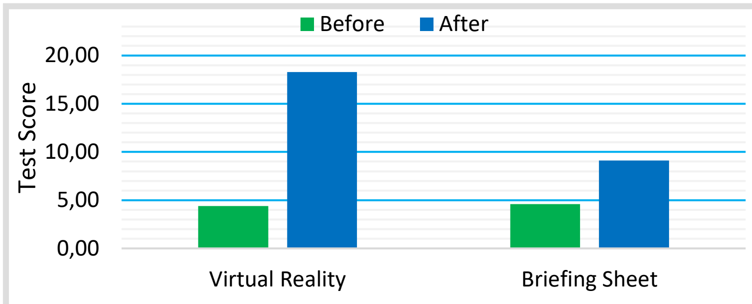

Figure 3: A comparison of average test scores before and after the VR and briefing sheet.

Discussion

Table 1 shows the learning performance of students for VR and the briefing sheet. The results before taking the test for both methods are similar, roughly 4 to 4.5 out of 23 for both; this is as expected. The total marks after the trials were largely different between the two methods; the briefing sheet averaging around 9 while the VR has an average score of around 18, this can be seen in figure 3. This is a significant difference between the two methods for test scores. This means that the scored of participants using VR improved by 10 marks higher than the traditional briefing sheet method, as shown in figure 4. VR scores improved from 17% to 78%, while briefing improved from 19% to 34%. Thus, a 44% improvement was made by using the VR method. After completing a T-test for each question it was seen that four questions to have a greater than 99% significance level, one question had greater than 95% significance, two questions had greater than 90% significance, and no significant difference was found for three questions. Overall, this gives statistical evidence that using VR improved the test scores. For the questionnaire results, only three questions did not give statistical evidence, with a further two giving only weak evidence. From the remainder, five questions give statistical evidence and thirteen give strong statistical evidence.

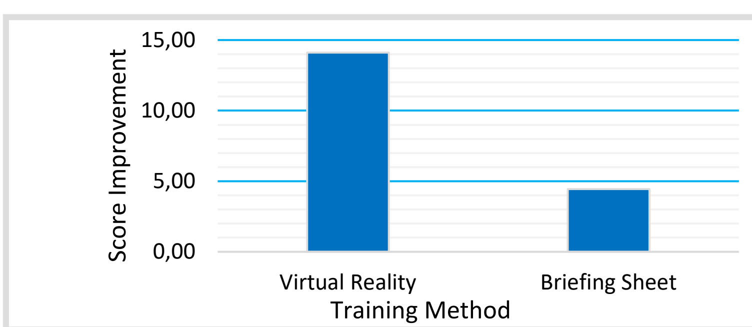

Figure 4: A comparison between the average improvement of VR and briefing sheet

Acceptance and Usage

Table 2: Comparison of the attitude UTAUT questionnaire answers on a scale of 1, strongly disagree, to 7, strongly agree, between VR and briefing sheet.

	Virtual Reality Participants											Briefing Sheet Participants										
Question	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	Average	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	Average
Attitude 1	5	4	7	7	7	7	7	7	7	7	**6.5**	7	6	4	4	6	3	3	2	6	5	**4.6**
Attitude 2	5	7	7	7	7	7	7	7	7	7	**6.8**	2	6	2	3	4	3	2	1	3	1	**2.7**
Attitude 3	6	7	7	7	7	7	7	7	7	7	**6.9**	2	6	1	2	4	3	2	1	3	1	**2.5**
Attitude 4	5	6	7	7	7	7	7	7	7	7	**6.7**	4	6	2	4	5	3	2	1	4	2	**3.3**

Discussion

Table 2 is the results from the attitude section of the post-trial questionnaire. These results have been illustrated in figure 5, and it shows, in general, the VR candidates believed they had a much better attitude towards learning than the briefing sheet candidates had. The first question asks if the method they used is a good idea, VR candidates strongly agreed VR was while briefing sheet candidates remained neutral. The second and third question asks if their method makes work more interesting and if working with that method is fun, respectively. VR agreed slightly more than in question one, while the briefing sheet seemed to disagree. Lastly, question four asked if they liked working with the system and while the VR candidates strongly agreed, the briefing sheet candidates slightly disagreed.

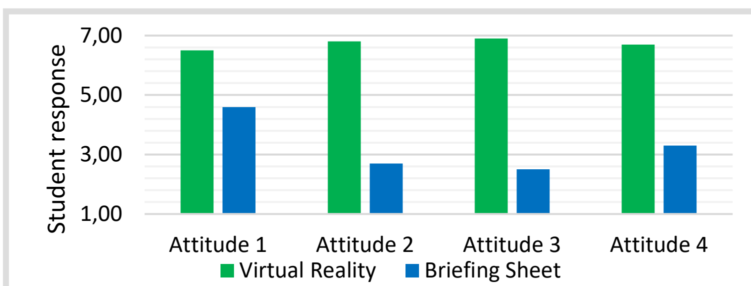

Figure 5: Comparison between the attitude of VR and briefing sheet questionnaire answers.

These results show that those using VR found the system to be interesting and fun. However, the briefing sheet candidates' answers suggest the contrary. A T-test shows these findings to have over 99% significance. A comment received by one of the students stated that technology like this would be very useful to first- and second-year undergraduate engineers, and if it were built into the course it could help the students enjoy the laboratory more and take more from it. On the other hand, these results may be biased by the fact that VR is a new and interesting technology. Therefore, a longer-term study should be conducted to eliminate this uncertainty.

CONCLUSIONS

The VR participants showed a bigger improvement to the briefing sheet. The virtual laboratory shown in figure 1 gave students a detailed experience of the laboratory. The tutorial guided students through each section of the lab, giving them instructions on what to do and why. This means that the students can learn more easily, allowing them to benefit from the real laboratory much more. Those using the briefing sheet did not achieve the same marks as those who used the VR, thus they take less away from the laboratory. The questionnaire results show that students are more engaged and perform better when using the VR method as opposed to the briefing sheet. It can also be seen that students are confident in using the system and would like to use it if it was made available to them. Overall, this technology is still new and developing, but these results show that it may have a significant benefit in education, specifically in engineering training and teaching.

FUTURE WORK

The virtual laboratory application created for this project was made by an individual with only basic experience in coding and game designing. Thus, the result is only a basic version of what could be achieved with a larger investment. The results may improve with a more sophisticated application, as the controls, features, and information included would far exceed that given in this study. The real benefit of VR comes from the ability to do anything desired, demonstrating things not possible in the real experiment. An example of this is the internals of the pipes, and a visualisation of the flow being available to the participant. Features such as this would allow the students to be able to explore and understand much more of the theory than in the real version of the laboratory. It is recommendable that further research within this subject is conducted to determine if a more advanced application would give greater benefits.

As e-learning is becoming more popular within education, these solutions also provide a more active approach; which may give students the experience needed to succeed in complex subjects. It is necessary to compare VR training methods to other e-learning methods, such as videos or interactive demonstrations, to see if the experience makes a significant improvement to an understanding over these cheaper, readily available e-learning methods. If it does, then the investment in this technology is justified.

The use of VR expands beyond secondary and undergraduate education. There are use cases where higher costs and danger are involved. VR reduces the risk and greatly reduces the cost while giving participants a realistic and familiar training session. Training for heavy machinery, complex manufacturing lines, or delicate machinery could be done using VR. Given the trend of current research, it may be as effective if not more, so much so that it has already been adopted by some companies already and is used as their official training course.

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BIOGRAPHICAL INFORMATION

Mr Timothy Hatchard is an undergraduate mechanical engineering student at The University of Warwick. He is currently conducting research with virtual reality to investigate if it is a more effective method of teaching and training in engineering education.

Dr Freeha Azmat is senior teaching fellow and course director for the Digital Technology Solutions Degree apprenticeship in Warwick Manufacturing Group (WMG). She joined WMG after completing her PhD in Engineering funded by University of Warwick Chancellors scholarship award. Before joining WMG, she completed a master’s in computer science from University of Leicester, where she was given Best student Award and Best project Award. She has also taught electronics and Micro-controller applications at Coventry University.

Dr Mohammad Al-Amin is Senior Teaching Fellow in WMG at the University of Warwick. He completed a PhD at Warwick with Best Thesis Award. Previously, he received a BSc. degree in Mechanical Engineering from the Bangladesh University of Engineering and Technology, Bangladesh, in 2005 and a MSc. degree in Sustainable Energy Technologies from University of Southampton, UK in 2010. From 2010 to 2013, he worked as an Assistant Process Manager at Solon International in Fujairah, UAE, the largest solar cell and module manufacturer in the Middle East.

Dr Zeina Rihawi is Senior Teaching Fellow at WMG, Warwick University. She received her PhD and MSc in Electronic Systems and Communication from Warwick University in 2016 and 2010 respectively. Her main research interests are in the field of optical wireless communications, in-vehicle networks and multimedia communications

Dr Alaa Al Sebae is Senior Teaching Fellow at WMG, Warwick University. He received a BSc. degree in Electrical and Mechanical engineering and specialized in Automated Control Systems and Computers. He has obtained his MSc degree in Electronic Systems with Communications and Ph.D. in computer networks from the school of engineering, Warwick University, Coventry, UK. From 2010 to 2011, he worked as a teaching assistant in signal processing lab at Warwick University. He also worked as teaching assistant, course leader and programme manager in the years between 2013 and 2017.

Corresponding Author

Mr. Timothy Michael Hatchard
The University of Warwick
School of Engineering
Coventry, CV4 7AL
07719 616409
T.Hatchard@Warwick.ac.uk