KARYA ILHAM PUBLISHING
CONNECTING MINDS, BRIDGING IDEAS, INSPIRING READERS

International Journal of Advanced Research in Computational Thinking and Data Science

Journal homepage:
https://karyailham.com.my/index.php/ctds/index
ISSN: 3030-5225

Performance Analysis of Light Detection and Ranging (LIDAR) in Augmented Reality (AR)

Muhammad Iskandar Sa'at[1], Azura Hamzah[1,*], Ahmad Haziq Aiman Rosol[1], Mahroof Mohamed Mafroos[2]

[1] Department of Electronic Systems Engineering Malaysia-Japan International Institute of Technology (MJIIT) Universiti Teknologi Malaysia (UTM) Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia
[2] Division of Electrical, Electronics and Telecommunication Engineering Technology, Institute of Technology University of Moratuwa, Sri Lanka

ARTICLE INFO

Article history:
Received 15 June 2024
Received in revised form 25 August 2024
Accepted 3 September 2024
Available online 15 September 2024

Keywords:
Light Detection and Ranging; LIDAR; Augmented Reality (AR)

ABSTRACT

Augmented reality (AR) has existed for decades, dating back from roughly 50 years ago when the renowned 'father of computer graphics' Ivan Sutherland first invented an AR head-mounted display system. Ever since, various organizations strive to improve the technology but while the AR technology definitely evolved significantly since its advent, the technology progress is relatively stagnant these past few years whereby we see little to no usage at least from common end user perspective. This may be due to various limitations of technologies currently utilized in AR. However, things may change since in 2020, the tech giant, Apple Inc. has made an unprecedented breakthrough by including the light detection and ranging (LiDAR) scanner on consumers' smartphones which could potentially revolutionize the AR industry. This research primarily revolves around analyzing the performance of utilization of LiDAR technology in AR mainly in mobile devices available for the mass. The methodology and concept for this research is fairly straight-forward, the AR experience boosted by the newly introduced LiDAR technology will be compared with the widely used technology which primarily consist of the implementation of Simultaneous Localization and Mapping (SLAM) and RGB camera with the exclusion of LiDAR and assessing the potential of LiDAR to further improvise AR experience and implementation in various fields. Testing results has shown significant improvement from various important aspects in AR whereby occlusion is possible in object rendering, the estimations based on live visual stimuli accuracy at roughly 99% in comparison to the true values as well as the ability to accurately perceive the geometry of objects in the real world environment through advanced depth and space perception.

1. Introduction

Augmented reality (AR) enhances a real-world environment by integrating computer-generated perceptual information, often across multiple sensory modalities including visual, auditory, haptic, somatosensory, and olfactory [1-4]. AR has been considered one of the most awe-inspiring

[*] *Corresponding author.*
E-mail address: azurahamzah@utm.my

https://doi.org/10.37934/ctds.3.1.3239a

breakthroughs in technological advancement. However, integrating components of the virtual world with reality presents significant challenges. Despite AR's boundless potential, extending into countless applications, little significant advancement has been observed over the last few decades (5, 6). This lack of progress can be attributed to AR being perceived as a distant and extravagant technology, more akin to science fiction, while the current AR technology remains limited and unappealing to the general public [7,8]. Common limitations include "sticker-like" AR object rendering and a lack of occlusion, where virtual objects simply overlap real-world images, reducing the immersive experience [9,10].

Recent advancements in data processing reliability and environmental perception have played a crucial role in advancing AR technology [11]. The incorporation of Light Detection and Ranging (LiDAR) sensors in mobile devices, as exemplified by Apple Inc.'s adoption in 2020, represents a significant leap forward. LiDAR technology, traditionally associated with high costs, now has the potential to revolutionize AR by providing enhanced depth perception and spatial awareness [12]. The synergy between AR and LiDAR is poised to address critical challenges in AR applications, particularly in improving spatial understanding and object interaction. By leveraging LiDAR's capabilities, AR experiences are expected to become more immersive and realistic, bridging the gap between the virtual and physical worlds [13].

To address these issues, aspects such as the reliability of data processing for reality augmenting processes and environmental perception must be considered. AR technology has been significantly limited by the hardware accessible to the public. However, a breakthrough occurred in 2020 when Apple Inc., a trendsetter in technological advancements, included a light detection and ranging (LiDAR) sensor in their lineup of mobile devices, albeit only in higher-end models [2,14,15]. This inclusion marks a potential revolution for the AR industry [16]. LiDAR systems, previously known for their high cost in fields such as automotive, are now available to the mass market. LiDAR technology estimates the distance between an origin and an obstacle or surface by targeting the surface with a laser and measuring the time taken for the reflected laser to return to the receiver. Although the combination of AR and LiDAR is unprecedented, the theoretical synergy of these technologies is expected to resolve significant issues in AR, such as space and environmental perception. The inclusion of LiDAR, which enhances depth perception, is anticipated to significantly improve the AR experience [17-19].

This research aims to evaluate the newly implemented LiDAR technology in AR, comparing it to previously and widely utilized technologies. Specifically, the objectives are to assess the performance improvements in AR applications with LiDAR technology, compare the accuracy and reliability of LiDAR-enhanced AR with traditional SLAM-based AR, and analyze the potential applications and implications of LiDAR in various AR fields. This study is significant as it explores the potential of LiDAR technology to revolutionize AR, making it more accessible and appealing to the masses. Improved depth perception and environmental interaction could enhance various applications, from gaming and education to industrial and medical fields [20].

The research will utilize both Android and iOS devices, comparing AR applications developed with Google ARCore and Apple ARKit, respectively. Performance metrics such as rendering quality, occlusion handling, and measurement accuracy will be evaluated. The study is expected to demonstrate significant improvements in AR performance with LiDAR technology, providing a more immersive and accurate AR experience. These findings could pave the way for broader adoption and innovation in AR applications.

2. Methodology

To achieve the objectives set for this research, smartphones were selected as the test subjects. This decision was made to test available AR technologies and services accessible to the general public, as this research focuses on the utilization of AR across various sectors, rather than being limited to specific industries or involving extremely expensive and high-end equipment. The broader focus of this research includes evaluating the potential utilities for end consumers. The test subjects for this research included a Google LLC-powered Android device and an Apple Inc.-powered iOS device, both equipped with LiDAR. Testing was conducted by running AR applications on these devices, developed using their respective AR software development kits: Google ARCore and Apple ARKit.

Due to differences in operating systems, the same app could not be tested on both devices. Instead, highly reputable, similarly functioning apps were selected for testing, and several aspects were highlighted for analysis. The tests were divided into three stages based on these highlighted aspects. In Stage 1, the focus was on object rendering and occlusion. A highly reputable AR object rendering application from the Google Play Store, ARLOOPA, was tested against a similarly capable application from the Apple App Store, IKEA Place. This app was highlighted by Apple Inc. during the reveal of LiDAR inclusion in their mobile devices. The tests considered the quality of the render, performance under different conditions, occlusion handling, and the overall user experience in operating the apps to achieve the same objectives.

In Stage 2, the theme was the reliability of data processing in estimations and information extraction from visual images. As AR primarily revolves around understanding the real world through machine vision, this stage aimed to compare the devices' ability to perceive and extract information from visual sources for augmentation, which is crucial for immersion and overall user experience. To test this capability, AR-based measurement apps were selected. ARuler, a reputable app from the Google Play Store, was chosen for Google devices, and Apple's Measure app was selected for iOS devices. Additionally, a 3D scanning-based measurement app, 3D Scanner App, exclusive to LiDAR-equipped devices, was included in this stage. The test began by measuring selected objects of different sizes and categories using traditional methods (measuring tape/ruler), followed by measurements using each respective app at two different distances from the object to verify the impact of visual changes on the measurements obtained. The acceptable range of measurements obtained through repetitions was tabulated, compared, and analyzed. Figure 1 outlines the objects chosen, the criteria for categorization, and the simplified overall test flow.

Table 1
Category of object to be measured

Category	Object (Horizontal)	Object (Vertical)
Small (< 10 cm)	AA Battery	AA Battery
Medium (> 10cm < 1 m)	Tiles	Shampoo Bottle
Large (> 1 m)	Door	Gaming Table
Distance Measurement (Camera/LiDAR Scanner)		
Reference Height/Object	Distance Toward	
1.5L Mineral Water Bottle	Ground	
Gaming Table		
Door		

In Stage 3, the focus was on depth and environmental perception. For virtual objects to blend seamlessly with reality, reliable and intelligent environmental perception is essential. Apple Inc. addressed the depth and space perception challenge by including a LiDAR scanner in their devices, while Google LLC optimized their software to enhance simultaneous localization and mapping (SLAM) through the use of RGB cameras and motion sensors, developing the Google ARCore Depth API. Apps developed by the respective companies were utilized for this stage: ARCore Depth Lab by Google and Clips by Apple. The Clips app features an exclusive AR planes capability for LiDAR-equipped devices, enabling users to scan a plane for AR effects deployment. ARCore Depth Lab offers various interactive AR effects, seemingly targeted more at developers than end consumers. This stage tested each app's ability to perceive the environment and visualize respective AR effects. Tests were conducted in a controlled environment built using weight plates to resemble stairs, allowing the devices to detect differences in multilevel heights and object arrangements, as depicted in Figure 1.

By conducting these stages of testing, the research aims to provide a comprehensive evaluation of the newly implemented LiDAR technology in AR, comparing it to previously and widely utilized technologies, and assessing its potential to revolutionize AR applications for broader adoption and innovation.

Fig. 1. Testing environment setup for the space and depth perception test (Stage 3)

3. Results

This section compiles the results obtained from the testing at various stages as detailed in the previous section. The summarized main and most significant findings of the testing phase of the research are presented below.

Phase 1 : Rendering and Occlusion Tests

Figure 2 shows the object rendering using the ARLOOPA app developed using Google ARCore without the LiDAR technology on Android platform. This render is achieved by using SLAM and visual reliant plane detection. On the other hand, the following Figure 3 shows the result on object rendering on the IKEA Place app which was developed on Apple ARKit with the inclusion of LiDAR scanner. Results on both figures show the base AR object rendering on the left hand side and the result of occlusion test on the right hand side of the figure.

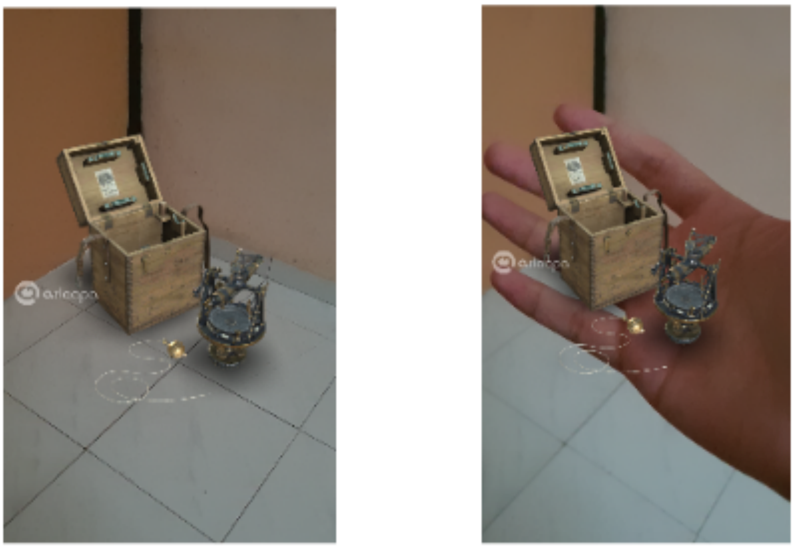

Fig. 2. Object rendering and occlusion test on device without LiDAR

Fig. 3. Object rendering and occlusion test on device with LiDAR

Phase 2 : Information Processing and Estimation Reliability Tests

Table 2 shows the tabulated data on measurements using traditional methods (measuring tape/ruler) depending on the size of the object and the measurements using each respective app with AR technologies. The ‘ ~ ’ notation on the table denotes the unreliability/instability in the value of the measurement through multiple repetition as such was deemed to indicate ‘failure in measurement’ due to the hardware/software limitations.

Table 2
Measurement of objects measured using various method

Horizontal Measurement, Length/Width (cm)							
Object	Ruler/ Measuring Tape	SLAM (ARuler)		SLAM + LiDAR (Measure)		LiDAR (3D Scanner App)	
Distance From Camera to Object	-	About 0.5 m	About 1-1.5 m	About 0.5 m	About 1-1.5 m	About 0.5 m	About 1.5 m
AA Battery	4.9	5	5	5	5	5	4
Mosaic Tile	30	±39	30	30	30	28	30
Gaming Table	140	~	±143	140	140	140	140
Vertical Measurement, Height (cm)							
Object	Ruler/ Measuring Tape	SLAM (ARuler)		SLAM + LiDAR (Measure)		LiDAR (3D Scanner App)	
Distance From Camera to Object	-	About 0.5 m	About 1-1.5 m	About 0.5 m	About 1-1.5 m	About 0.5 m	About 1-1.5 m
AA Battery	4.9	5	5	5	5	5	5
Shampoo Bottle	21.4	22	21	21	22	20	21
Door	203.5	~	203	203	203	200	200
Distance Measurements, Vertical Measurement from Reference Object's Height to the Ground (cm)							
Reference Object		Measuring Tape		ARuler		LiDAR Measuring	
1.5L Mineral Water Bottle		30		30		30.1	
Gaming Table		75		78		75	
Door		203.5		208		203	

Phase 3 : Depth Perception Tests

Figure 4 shows the depth and environmental perception tests results on ARCore Depth Lab app without the LiDAR scanner whereby the left-hand side of the figure shows the AR object from 1 perspective/viewing angle and the right-hand side of the figure shows the AR object from another viewing angle. Meanwhile, Figure 5 shows the depth and environmental perception tests results on the Clips app AR effect as well as the visualization of the world perception through LiDAR scanning.

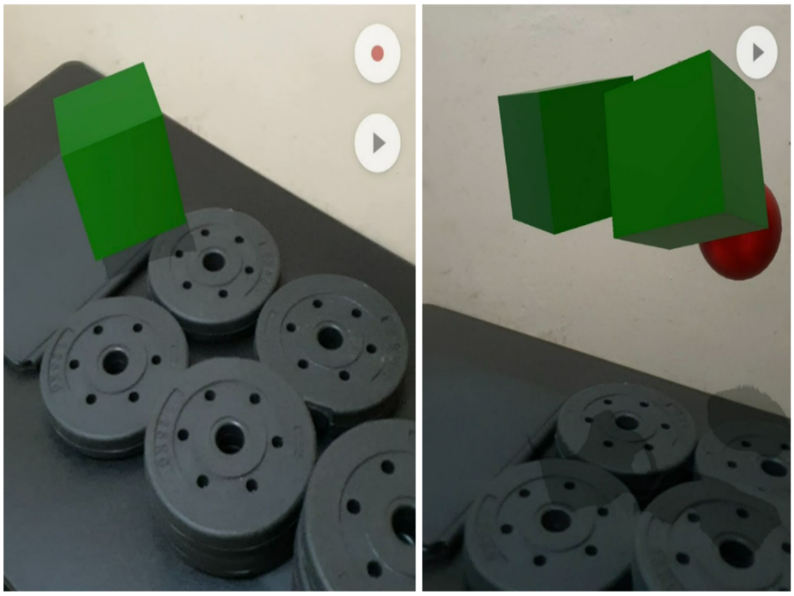

Fig. 4. Depth and Environmental Perception Test of Device without LiDAR

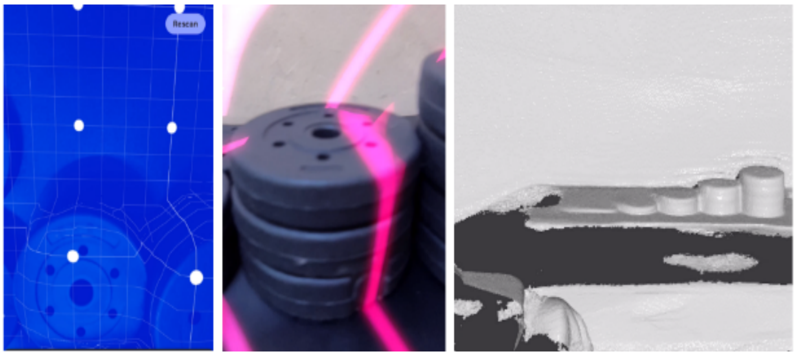

Fig. 5. Depth and Environmental Perception Tests of LiDAR Equipped Device

4. Conclusions

Based on the results of the various tests conducted, it can be concluded that while the inclusion of LiDAR in AR devices does enhance certain aspects of the AR experience, the overall improvement is not yet significant enough to justify the increased cost at this time. The depth and space perception capabilities of LiDAR-equipped devices are clearly superior to those without the LiDAR scanner, providing a more accurate and immersive AR experience. However, the full potential of LiDAR in AR has not yet been realized, as the current applications and software optimizations are still in the early stages of development. Despite the limited immediate impact, the future potential of LiDAR technology in AR is enormous. As developers continue to innovate and create more sophisticated applications that fully leverage LiDAR's capabilities, it is expected that the benefits of this technology will become more apparent. The improved depth sensing and spatial understanding provided by LiDAR have the potential to revolutionize AR applications across various fields, including gaming, education, industrial design, and medical training. In conclusion, while the current state of LiDAR integration in AR may not yet offer a compelling advantage for the average consumer, its superior depth and space perception capabilities hold great promise for the future. Continued advancements in software and application development are likely to unlock the full potential of LiDAR, making it a valuable addition to AR technology and paving the way for more immersive and accurate AR experiences. As the technology matures and becomes more cost-effective, LiDAR is poised to become a standard feature in AR devices, transforming the way we interact with and perceive the digital world overlaid on our physical environment.

Acknowledgement
This research work is funded by the Universiti Teknologi Malaysia under UTM Fundamental Research (Q.K130000.3843.22H96).

References
[1] L Lu, Jianfeng, Li Li, and Goh Poh Sun. "A multimodal virtual anatomy e-learning tool for medical education." In *Entertainment for Education. Digital Techniques and Systems: 5th International Conference on E-learning and Games, Edutainment 2010, Changchun, China, August 16-18, 2010. Proceedings 5*, pp. 278-287. Springer Berlin Heidelberg, 2010. https://doi.org/10.1007/978-3-642-14533-9_28
[2] Nijholt, Anton. "Virtual and Augmented Reality Animals in Smart and Playful Cities." In *2020 Joint 9th International Conference on Informatics, Electronics & Vision (ICIEV) and 2020 4th International Conference on Imaging, Vision & Pattern Recognition (icIVPR)*, pp. 1-7. IEEE, 2020. https://doi.org/10.1109/ICIEVicIVPR48672.2020.9306528
[3] Yang, Younghwan, Junhwa Seong, Minseok Choi, Junkyeong Park, Gyeongtae Kim, Hongyoon Kim, Junhyeon Jeong et al. "Integrated metasurfaces for re-envisioning a near-future disruptive optical platform." *Light: Science & Applications* 12, no. 1 (2023): 152. https://doi.org/10.1038/s41377-023-01169-4

[4] Morales Méndez, Ginés, and Francisco del Cerro Velázquez. "Augmented Reality in Industry 4.0 Assistance and Training Areas: A Systematic Literature Review and Bibliometric Analysis." *Electronics* 13, no. 6 (2024): 1147. https://doi.org/10.3390/electronics13061147

[5] Juan, M. C., Cristina Botella, M. Alcaniz, R. Banos, C. Carrion, M. Melero, and José Antonio Lozano. "An augmented reality system for treating psychological disorders: application to phobia to cockroaches." In *Third ieee and acm international symposium on mixed and augmented reality*, pp. 256-257. IEEE, 2004.

[6] Meng, Yuan, Yizhen Chen, Longhui Lu, Yimin Ding, Andrea Cusano, Jonathan A. Fan, Qiaomu Hu et al. "Optical meta-waveguides for integrated photonics and beyond." *Light: Science & Applications* 10, no. 1 (2021): 1-44. https://doi.org/10.1038/s41377-021-00655-x

[7] DiVerdi, Stephen, and Tobias Hollerer. "Groundcam: A tracking modality for mobile mixed reality." In *2007 IEEE Virtual Reality Conference*, pp. 75-82. IEEE, 2007. https://doi.org/10.1109/VR.2007.352466

[8] Kasinathan, Vinothini, Afnan Taha Abdullah Al-Sharafi, Aida Zamnah, Naresh Kumar Appadurai, Vinesh Thiruchelvam, and Aida Mustapha. "Augmented reality in ocean's secrets: educational application with attached book for students." *Linguistics and Culture Review* 5, no. S1 (2021): 1123-1137. https://doi.org/10.21744/lingcure.v5nS1.1498

[9] Kato, Hirokazu, Mark Billinghurst, Ivan Poupyrev, Kenji Imamoto, and Keihachiro Tachibana. "Virtual object manipulation on a table-top AR environment." In *Proceedings IEEE and ACM International Symposium on Augmented Reality (ISAR 2000)*, pp. 111-119. Ieee, 2000.

[10] Cooper, Nicholas, Aaron Keatley, Maria Dahlquist, Simon Mann, Hannah Slay, Joanne Zucco, Ross Smith, and Bruce H. Thomas. "Augmented reality chinese checkers." In *Proceedings of the 2004 ACM SIGCHI International Conference on Advances in computer entertainment technology*, pp. 117-126. 2004. https://doi.org/10.1145/1067343.1067357

[11] Sivanesan, Vighnesh, Zhen Lu Ng, Tong Xir Lim, Hong Kai Tan, Kai Shen Yew, and Wei Wei Goh. "The Use of Augmented Reality in Collaboration Within the Construction Industry." In *Journal of Physics: Conference Series*, vol. 2120, no. 1, p. 012032. IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/2120/1/012032

[12] Perez, Alfredo J., and Sherali Zeadally. "Recent advances in wearable sensing technologies." *Sensors* 21, no. 20 (2021): 6828. https://doi.org/10.3390/s21206828

[13] Yeztiani, Olvi Lorensky, Qadhli Jafar Adrian, and Ahmad Ari Aldino. "Application of Augmented Reality As a Learning Media of Mollusca Group Animal Recognition and Its Habitat Based on Android." *Jurnal Teknoinfo* 16, no. 2 (2022): 420-426. https://doi.org/10.33365/jti.v16i2.2044

[14] Uva, Antonio E., Michele Gattullo, Vito M. Manghisi, Daniele Spagnulo, Giuseppe L. Cascella, and Michele Fiorentino. "Evaluating the effectiveness of spatial augmented reality in smart manufacturing: a solution for manual working stations." *The International Journal of Advanced Manufacturing Technology* 94 (2018): 509-521. https://doi.org/10.1007/s00170-017-0846-4

[15] Lopatin, Anton, Oleg Dubovik, David Fuertes, Georgiy Stenchikov, Tatyana Lapyonok, Igor Veselovskii, Frank G. Wienhold, Illia Shevchenko, Qiaoyun Hu, and Sagar Parajuli. "Synergy processing of diverse ground-based remote sensing and in situ data using the GRASP algorithm: applications to radiometer, lidar and radiosonde observations." *Atmospheric Measurement Techniques* 14, no. 3 (2021): 2575-2614. https://doi.org/10.5194/amt-14-2575-2021

[16] Rombaut, Juan, Sofia Martinez, Umberto Maria Matera, Prantik Mazumder, and Valerio Pruneri. "Antireflective multilayer surface with self-cleaning subwavelength structures." *ACS photonics* 8, no. 3 (2021): 894-900. https://doi.org/10.1021/acsphotonics.0c01909

[17] Malý, Ivo, David Sedláček, and Paulo Leitao. "Augmented reality experiments with industrial robot in industry 4.0 environment." In *2016 IEEE 14th international conference on industrial informatics (INDIN)*, pp. 176-181. IEEE, 2016. https://doi.org/10.1109/INDIN.2016.7819154

[18] Bordegoni, Monica, Marina Carulli, and Yuan Shi. "Investigating the use of smell in vehicle-driver interaction." In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, vol. 50077, p. V01AT02A053. American Society of Mechanical Engineers, 2016.

[19] Ranasinghe, Nimesha, Thi Ngoc Tram Nguyen, Yan Liangkun, Lien-Ya Lin, David Tolley, and Ellen Yi-Luen Do. "Vocktail: A virtual cocktail for pairing digital taste, smell, and color sensations." In *Proceedings of the 25th ACM international conference on Multimedia*, pp. 1139-1147. 2017. https://doi.org/10.1145/3123266.3123440

[20] Marto, Anabela, Miguel Melo, Alexandrino Goncalves, and Maximino Bessa. "Multisensory augmented reality in cultural heritage: Impact of different stimuli on presence, enjoyment, knowledge and value of the experience." *IEEE Access* 8 (2020): 193744-193756. https://doi.org/10.1109/ACCESS.2020.3032379