AUGMENTED REALITY AND VIRTUAL REALITY IN

LIGHT ESTIMATION USING AUGMENTED REALITY

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1. Abstract

The Lighting Estimation API is a tool developed to help achieve accurate lighting in AR applications. It provides detailed information about the lighting conditions in a scene, which can be used to render virtual objects in a way that matches the lighting cues in the real environment.The API works by analyzing images captured by the device's camera and extracting information about the scene's lighting conditions, such as the intensity, direction, and color of light sources. This information can then be used to adjust the rendering of virtual objects to match the lighting conditions in the real world, making them appear more realistic and grounded.The Lighting Estimation API can be used in conjunction with Unity Engine, AR Foundation, and AR Core XR Plugin, which are popular development tools for AR applications. By integrating the API into these tools, developers can easily incorporate accurate lighting into their AR applications without having to develop complex lighting algorithms from scratch.

The Lighting Estimation API has been used in a variety of AR applications, such as gaming, retail, and interior design. For example, in a retail application, the API can be used to accurately render virtual products in different lighting conditions, allowing customers to see how the products will look in real life

***Keywords** : AR applications, Lighting Estimation API, accurate lighting, Unity Engine, AR Foundation,*

2. Introduction

In recent years, Augmented Reality (AR) and Virtual Reality (VR) have become increasingly popular due to their potential to create immersive and interactive experiences. AR technology overlays digital content onto the real world, while VR creates an entirely new simulated environment. Both technologies have revolutionized the way we interact with digital content and have a wide range of applications, including entertainment, education, training, and marketing.However, one of the key challenges in AR and VR is to accurately estimate lighting conditions to create a realistic experience. Lighting plays a crucial role in creating the illusion of reality and can significantly impact the effectiveness and quality of AR and VR experiences. Accurate lighting estimation is especially important when creating AR and VR applications that are intended to be used in real-world environments, where lighting conditions can vary significantly.

In this project report, we explore the use of AR in estimating lighting conditions for both AR and VR applications. We investigate how AR technology can be used to improve the accuracy of light estimation in real-world environments. By combining AR technology with light estimation techniques, we aim to create more realistic and immersive AR and VR experiences that are indistinguishable from the real world.The report is structured as follows. First, we provide a brief overview of AR and VR technology, including their applications and limitations. We introduce our proposed method, which uses AR to estimate lighting conditions for both AR and VR applications. We describe the implementation of our proposed method, the results obtained, and the evaluation of our method against existing techniques.Overall, this project report aims to demonstrate the potential of using AR to improve the accuracy of light estimation in AR and VR applications. Our proposed method has the potential to enhance the realism and quality of AR and VR experiences, making them more engaging and effective for a wide range of applications.

3.Literature Survey :

3.1 Frahm, Koeser, Grest, Koch - This research presents a markerless augmented reality system with intuitive positioning and realistic direct lighting of virtual objects.Their approach exploits a two camera system consisting of a TV-camera and a fish-eye camera. The TVcamera captures the video for the augmentation while the fish-eye camera observes the upper hemisphere to track the light sources. Accordingly, direct lighting can be used to render virtual objects. Additionally, This paper propose an easy method to place virtual objects in the scene and to compute the shadows of these objects. The proposed tracking methods overcome the limitations of many systems that need markers in the scene for augmentation or need additional equipment in the scene to reconstruct illumination.Their approach will keep the augmented scene unaffected.

3.2 AliceBellazzi, LauraBellia, D'Agostino, GiorgiaChinazzo, FedericaCorbisiero. - The achievement of a good visual environment is key to guaranteeing human satisfaction indoors. In this context, it is crucial to assess the visual environment through the measurement of human perception. This paper, the assessment of the visual environment through human perception is often complicated. Using real spaces or mock-ups is time consuming, costly, and does not allow the control of all possible variables (e.g., daylight). Photorealistic rendered images present several limitations, starting from the veracity of the visual stimulus presented to participants. Virtual Reality (VR) is emerging as a valid alternative for evaluating the perception of the indoor visual environment due to the ability to control selected variables, analyze cause -effect relationships, and save time and cost, especially for the evaluation of daylit spaces. The high level of immersion and the possibility of interaction provide an opportunity to study users' perceptions and behaviors. This paper, some aspects of light assessment in VR need further investigations, such as the comparability of the perception of light in real and virtual environments. This paper reviews the available literature on the topic, highlighting the advantages and disadvantages related to the use of VR for lighting research and design.

3.3 Celong Liu, Lingyu Wang, Zhong Li, Shuxue. - Augmented Reality (AR) applications aim to provide realistic blending .This paper the real-world and virtual objects. One of the important factors for realistic AR is the correct lighting estimation. In this paper, This paper present a method that estimates the real-world lighting condition from a single image in real-time, using information from an optional support plane provided by advanced AR frameworks (e.g. ARCore, ARKit, etc.). By analyzing the visual appearance of the real scene, Their algorithm could predict the lighting condition from the input RGB photo. In the first stage, This paper use a deep neural network to decompose the scene into several components: lighting, normal, and BRDF. Then This paper introduce differentiable screen space rendering, a novel approach to providing the supervisory signal for regressing lighting, normal, and BRDF jointly. This paper recover the most plausible real-world lighting condition using Spherical Harmonics and the main directional lighting. Through a variety of experimental results, This paper demonstrates that Their method could provide improved results than prior works quantitatively and qualitatively, and it could enhance the real-time AR experiences.

3.4 Hannes Kaufman , nTU Wien - This paper presents a novel method for illumination estimation from RGB-D images. The main focus of the proposed method is to enhance visual coherence in augmented reality applications by providing accurate and temporally coherent estimates of real illumination. For this purpose, This paper designed and trained a deep neural network which calculates a dominant light direction from a single RGB-D image. Additionally, they propose a novel method for real-time outlier detection to achieve temporally coherent estimates. their method for light source estimation in augmented reality was evaluated on the set of real scenes.Their results demonstrate that the neural network can successfully estimate light sources even in scenes which This paper does not see by the network during training. Moreover, they compared Their results with illumination estimates calculated by the state-of-the-art method for illumination estimation. Finally, they demonstrate the applicability of Their method on numerous augmented reality scenes.

3.5 Dan Wood , Brian Curless - A surface light field is a function that assigns a color to each ray originating on a surface. Surface light fields are suited to constructing virtual images of shiny objects under complex lighting conditions. This paper presents a framework for construction, compression, interactive rendering, and rudimentary editing of surface light fields of real objects. Generalizations of vector quantization and principal component analysis are used to construct a compressed representation of an object's surface light field from photographs and range scans. A new rendering algorithm achieves interactive rendering of images from the compressed representation, incorporating view-dependent geometric level-of-detail control. The surface light field representation can also be directly edited to yield plausible surface light fields for small changes in surface geometry and reflectance properties.

3.6 Zegang Wang - I am going to briefly compare two recent research papers, Xihe and GLEAM, that provide real-time lighting estimation on mobile devices. Lighting estimation, briefly,refers to obtaining lighting information from environment scenes.For augmented reality, the scenes are physical environments and therefore can have natural lighting condition changes, both temporally and spatially. Dynamic scene lighting is a key reason that lighting estimation for physical en-vironments is challenging. As lighting conditions can potentially change from one frame to the next, such rapid changes necessitate fast . Existing commercialAR platforms including ARCore and ARKit have started to provide lighting estimate APIs, such as the ARLightEstimate.This paper, existing supports are still at an early stage, only providing ambient light information for an entire scene. In other words, existing commercial AR platforms including ARCore and ARKit still lack supports for accurate lighting estimation and thus often result in unrealistic rendering effects. Below are two diagrams that demonstrate the rendering effects using lighting information provided by ARKit vs. GLEAM/Xihe. Both GLEAMand Xihe produce more visually coherent virtual objects.

3.7 Tomohiro Mashita , Osaka University - This paper introduce an in-situ lighting and reflectance estimation method that does not require specific light probes and/or preliminary scanning.Their method uses images taken from multiple viewpoints while data accumulation and lighting and reflectance estimations run in the background of the primary AR system. As a result,Their method requires little in the way of manipulations for image collection because it consists primarily of image processing and optimization. When used, lighting directions and initial optimization values are estimated via image processing. Eventually, the full parameters are obtained by optimization of the differences bet This paper and real images. This system uses current best parameters because the parameter estimation and input image updates are run independently.

3.8 Alexander Plopski - This paper present an approach which enables real-time augmentation of an environment composed of materials with different texture and reflectance properties without the need of application-specific hardware or extensive preparation.Their solution uses a set of RGB images of a reconstructed model to optimize the reflectance parameters and light location. Each image is decomposed into its specular and diffuse components and This paper estimates the location of multiple light sources from specular highlights. The environment is stored in a voxel grid and This paper optimizes the reflectance properties and color of each voxel through inverse rendering. This paper verifies Their approach with a simulated environment and presents results from a corresponding reconstructed environment.

3.9 Natalia Neverova - Lighting conditions estimation is a crucial point in many applications. This paper shows that combining color images with corresponding depth maps (provided by modern depth sensors) allows to improve estimation of positions and colors of multiple lights in a scene. Since usually such devices provide low-quality images, for many steps of Their framework This paper proposes alternatives to classical algorithms that fail when the image quality is low.Their approach consists in decomposing an original image into specular shading, diffuse shading and albedo. The two shading images are used to render different versions of the original image by changing the light configuration. Then, using an optimization process, This paper finds the lighting conditions allowing to minimize the difference between This paper the original image and the rendered one.

3.10 Jan Jachnik - A single hand-held camera provides an easily accessible but potentially extremely .This paper setup for augmented reality. Capabilities which previously required expensive and complicated infrastructure have gradually become possible from a live monocular video feed, such as accurate camera tracking and, most recently, dense 3D scene reconstruction. A new frontier is to work towards recovering the reflectance properties of general surfaces and the lighting configuration in a scene without the need for probes, omnidirectional cameras or specialized light-field cameras. Specular lighting phenomena cause effects in a video stream which can lead current tracking and reconstruction algorithms to fail. This paper, the potential exists to measure and use these effects to estimate deeper physical details about an environment, enabling advanced scene understanding and more convincing AR. This paper presents an algorithm for real-time surface light-field capture from a single hand-held camera, which is able to capture dense illumination information for general specular surfaces.Their system incorporates a guidance mechanism to help the user interactively during capture. This paper then splits the light-field into its diffuse and specular components, and shows that the specular component can be used for estimation of an environment map. This enables the convincing placement of an augmentation on a specular surface such as a shiny book, with realistic synthesized shadow, reflection and occlusion of specularities as the viewpoint changes.Their method currently works for planar scenes.

3.11 Souheil Hadj Said - Diminished Reality (DR) is a video editing technique that alters reality by removing certain objects. It can be used as a preliminary step in Augmented Reality to replace real objects by virtual ones with different sizes and shapes. It can also be used solely, for example, in the case of virtually emptying a furnished apartment. The general approach of DR consists of three main steps. First, an inpainting technique is applied to a target region in the image to coherently remove an object. The image corresponds to a keyframe of the video stream. Second, the resulting unpainted region is transmitted to the next frames of the video stream by copying pixel intensities with respect to the camera pose and scene geometry. This consists in estimating the camera orientation and position in 3D which can be obtained by a Simultaneous Localization and Mapping (SLAM) technique. Third, the target region is updated with respect to the lighting change in the scene.In this thesis, This paper focused on the third step of the DR pipeline. Although many DR applications have been proposed in the literature, few are the ones who dealt with light change in the scene. Most of past work assumes that the surface is Lambertian and therefore perfectly diffuse. This paper, this is often not true, especially in indoor environments. By identifying specular highlights as the main cause for lighting change in the target region, This paper proposed two main approaches to address this problem.First, This paper proposed a specularity propagation method applied to real-time DR. Using the DR pipeline mentioned earlier, This paper integrated an interpolation function based on Thin-Plate Splines (TPS) in order to estimate the change ratios of the pixel intensities in the target region. This function is constrained by a number of specularity properties to achieve a plausible reconstruction of the specular highlights in the video stream.Their approach was tested on several real-time videos and achieved coherent reproduction of specularities in the context of DR.Second, This paper addressed the lighting problem in DR and AR as an inverse rendering problem. To do so, This paper analyzed the image components as described in light reflection models. In Computer Graphics, local illumination models such as Phong’s are used to render synthetic images in real-time. In this case, the parameters of the model are set by the user as inputs along with the scene’s geometry, the light source configuration and the camera pose. This paper, in a Mixed Reality (MR) application, the parameters of the model are unknown and have to be set in concordance with the real image from the camera. So, in this case This paper wants to solve an inverse local illumination problem where the input is the real image. The output is the model’s parameters along with the light source configuration, the scene’s geometry and the camera pose. In this thesis, This paper proposed an exhaustive evaluation of the paper-posedness of this problem with a focus on the specular highlights. The camera pose and the scene’s geometry are estimated using the SLAM approach and the rest of the unknown parameters are estimated by minimizing a photometric cost. This paper can invert a local illumination model from the observation of a single specular highlight.

Therefore, in the context of AR and DR applications, This paper does not need to know the number of light sources in the scene a priori since each specularity is processed separately. This also opens many perspectives for similar inversion problems like camera localization.

3.12 Frédéric Bousefsaf - Here, the authors explore the potential of multispectral imaging applied to image completion. Snapshot multispectral cameras correspond to breakthrough technologies that are suitable for everyday use. Therefore, they correspond to an interesting alternative to digital cameras. In their experiments, multispectral images are acquired using an ultra compact snapshot camera recorder that senses 16 different spectral channels in the visible spectrum. Direct exploitation of completion algorithms by extension of the spectral channels exhibits only minimum enhancement. A dedicated method that consists in a prior segmentation of the scene has been developed to address this issue. The segmentation derives from an analysis of the spectral data and is employed to constrain the research area of exemplar-based completion algorithms. The full processing chain takes benefit from standard methods that This paper developed by both hyperspectral imaging and computer vision communities. Results indicate that image completion constrained by spectral pre-segmentation ensures better consideration of the surrounding materials and simultaneously improves rendering consistency, in particular for completion of flat regions that present no clear gradients and little structure variance. The authors validate their method with a perceptual evaluation based on 20 volunteers. This study shows for the first time the potential of multispectral imaging applied to image completion.

3.13 John Lin - The latest advancements in Augmented Reality (AR) and Diminished Reality (DR) the development of many consumer oriented applications (such as sales and driving aid, or education). To increase the realism in rendering, estimating the illumination in the scene is a key element. A lot of works tackle this problem but rarely discuss the color of the reconstructed illumination. The Dichromatic Model indicates that the specular component is not affected in color by the texture underneath and holds the light source's color. Though theoretically sound, in practice consumer cameras are subject to nonlinear behaviors which change RGB ratios and create inconsistencies when estimating the illumination. In this paper, This paper studies the conditioning and limits of inverting local illumination models while relying on the Dichromatic Model. This paper shows that the reconstructed specular component has an inconsistent color because it changes depending on the surface's colors.

3.14 Stamatios Georgoulis - In this paper,they present a method that estimates reflectance and illumination information from a single image depicting a single material specular object from a given class under natural illumination. This paper follows a data-driven, learning-based approach trained on a very large dataset, but in contrast to earlier work This paper does not assume one or more components (shape, reflectance, or illumination) to be known. This paper proposes a two-step approach, where This paper first estimates the object's reflectance map, and then further decomposes it into reflectance and illumination. For the first step, This paper introduce a Convolutional Neural Network (CNN) that directly predicts a reflectance map from the input image itself, as This paper as an indirect scheme that uses additional supervision, first estimating surface orientation and afterwards inferring the reflectance map using a learning-based sparse data interpolation technique. For the second step, This paper suggests a CNN architecture to reconstruct both Phong reflectance parameters and high-resolution spherical illumination maps from the reflectance map. This paper also proposes new datasets to train these CNNs. This paper demonstrates the effectiveness of Their approach for both steps by extensive quantitative and qualitative evaluation in both synthetic and real data. This paper is through numerous applications that show improvements over the state-of-the-art.

3.15 Sanni Siltanen - A modular real-time diminished reality pipeline for indoor applications is presented. The pipeline includes a novel inpainting method which requires no prior information of the textures behind the object to be diminished. The inpainting method operates on rectified images and adapts to scene illumination. In typically challenging illumination situations, the method produces more realistic results in indoor scenes than previous approaches. Modularity enables using alternative implementations in different stages and adapting the pipeline for different applications. Finally, practical solutions to problems occurring in diminished reality applications, for example interior design, are discussed.

3.16 Jia-Bin Huang - This paper proposes a method for automatically guiding patch based image completion using mid-level structural cues.Their method first estimates planar projection parameters, softly segments the known region into planes, and discovers translational regularity within these planes. This information is then converted into soft constraints for the low-level completion algorithm by defining prior probabilities for patch offsets and transformations. handles multiple planes, and in the absence of any detected planes falls back to a baseline fronto-parallel image completion algorithm. This paper validates Their technique through extensive comparisons with state-of-the-art algorithms on a variety of scenes.

3.17 A'Ishah Alhakamy , Mihran Tuceryan - A realistically inserted virtual object in the real-time physical environment is a desirable feature in augmented reality (AR) applications and mixed reality (MR) in general. This problem is considered a vital research area in computer graphics, a field that is experiencing ongoing discovery. The algorithms and methods used to obtain dynamic and real-time illumination measurement, estimating, and rendering of augmented reality scenes are utilized in many applications to achieve a realistic perception by humans. This paper cannot deny the impact of the continuous development of computer vision and machine learning techniques accompanied by the original computer graphics and image processing methods to provide a significant range of novel AR/MR techniques. These techniques include methods for light source acquisition through image based lighting or sampling, registering and estimating the lighting conditions, and composition of global illumination. In this review, This paper discussed the pipeline stages with the details elaborated about the methods and techniques that contributed to the development of providing photo-realistic rendering, visual coherence, and interactive real-time illumination results in AR/MR.

3.18 Bui Tuong Phong - The quality of computer generated images of three-dimensional scenes depends on the shading technique used to paint the objects on the cathode-ray tube screen. The shading algorithm itself depends in part on the method for modeling the object, which also determines the hidden surface algorithm. The various methods of object modeling, shading, and hidden surface removal are thus strongly interconnected. Several shading techniques corresponding to different methods of object modeling and the related hidden surface algorithms are presented here. Human visual perception and the fundamental laws of optics are considered in the development of a shading rule that provides better quality and increased realism in generated images.

4.1 METHODOLOGY

The methodology for implementing the Lighting Estimation API in an AR experience using Unity Engine can be outlined as follows:

(i) Set up the development environment: Install the required tools and software, including Unity Engine 2020.3.40f1, AR Foundation 4.2.7.

(ii) Import the Lighting Estimation API: Import the Lighting Estimation API package into the Unity project.

(iii) Configure the AR camera: Set up the AR camera to enable environmental understanding and the detection of light probes.

(iv) Add virtual objects: Import the 3D models of virtual objects into the Unity project, and add them to the AR scene.

(v) virtual objects with lighting cues: Use the Lighting Estimation API to analyze the lighting conditions in the scene and to apply those conditions to the virtual objects. This will ensure that the virtual objects are rendered under the same lighting conditions as the physical scene.

(vi) Test and refine: Test the AR experience on different devices and in different lighting conditions. Refine the implementation as necessary to ensure that the virtual objects are realistically lit and blend seamlessly with the physical environment.

Overall, this methodology allows developers to create realistic AR experiences by analyzing the lighting conditions in the physical environment and applying those conditions to virtual objects in real-time using the Lighting Estimation API

4.2 Comparison :

The Lighting Estimation API provides a more detailed and accurate representation of the lighting in a scene compared to traditional methods of lighting virtual objects in AR. With the API, developers can obtain information about the direction, intensity, and color temperature of the ambient light, as well as any directional light sources. This information can be used to create more realistic shadows, reflections, and highlights on virtual objects.

In contrast, traditional methods of lighting virtual objects in AR rely on manually setting the lighting conditions based on visual inspection of the environment. This can lead to inconsistencies between the virtual and real worlds, resulting in a less immersive and realistic AR experience.

5. MATHEMATICAL CONCEPT

The mathematical concepts of transformation, linear transformation, uniform scaling, rotation, and shearing with the Lighting Estimation API in AR/VR development can improve the realism and accuracy of virtual objects in the physical environment. Here are some ways to do it:

1. Transformation and Linear Transformation: The Lighting Estimation API provides detailed data on the lighting in a scene, which can be used to transform and linearly transform the virtual objects to fit into the scene seamlessly. This can be done by using the transformation and linear transformation matrices derived from the lighting data to adjust the position, orientation, and scale of the virtual objects.
2. Uniform Scaling: Uniform scaling can be used to adjust the size of virtual objects based on the lighting conditions in the scene. This can be done by using the Lighting Estimation API to determine the overall brightness of the scene and scaling the virtual objects accordingly.
3. Rotation: The Lighting Estimation API can provide data on the direction and intensity of light sources in the scene, which can be used to rotate virtual objects in the correct direction and angle. This can improve the accuracy of shadow placement and make the virtual objects look more natural.
4. Shearing: Shearing can be used to adjust the shape of virtual objects based on the lighting conditions in the scene. This can be done by using the Lighting Estimation API to determine the angles of the light sources and applying shearing matrices to the virtual objects to match those angles.

The equations for some of these transformations are:

(i) Uniform scaling : Let S be the scaling factor.If (x,y,z) is a point in 3D space, then the scaled point (x',y',z') is given by:

$x' = Sx$

$y' = Sy$

$z' = S*z$

(ii) Rotation: Let θ be the angle of rotation and (u,v,w) be the axis of rotation.If (x,y,z) is a point in 3D space, then the rotated point (x',y',z') is given by:

$x' = (\cos\theta + u^2(1-\cos\theta))x + (uv(1-\cos\theta) -w\sin\theta)y + (uw(1-\cos\theta)+v\sin\theta)z$

$y' = (uv(1-\cos\theta)+w\sin\theta)*x + (\cos\theta+v^2 (1-\cos\theta))y + (vw(1-\cos\theta)-u\sin\theta)z$

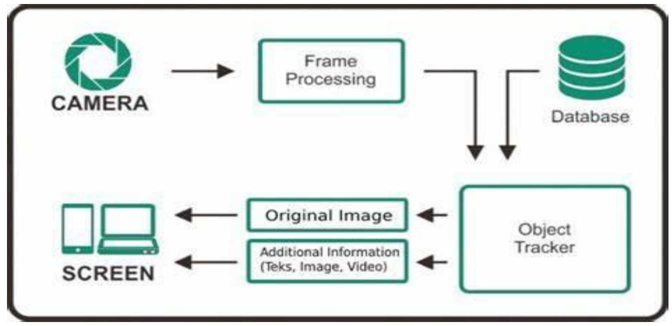
$z' = (uw(1-\cos\theta)-v\sin\theta)x + (vw(1-\cos\theta) + u\sin\theta)*y + (\cos\theta+w^2(1-\cos\theta))*z.$

(iii) Shearing : Let k be the shearing factor along the x-axis.
If (x,y,z) is a point in 3D space, then the sheared point (x',y',z') is given by:

$x' = x + k*y$

$y' = y$

$z' = z$



6. Workflow :

The workflow of the Lighting Estimation API starts with capturing images of the real-world environment using the camera on an AR device. These images are then fed into the API, which analyzes them and extracts detailed information about the lighting conditions in the scene, including the intensity, direction, and color of light sources. This information is then used to adjust the rendering of virtual objects in the AR application, so that they match the lighting cues in the real environment.
To use the Lighting Estimation API in an AR application, developers can integrate it with popular development tools such as Unity Engine, AR Foundation, and AR Core XR Plugin. This integration allows developers to easily incorporate the API's lighting information into their applications without having to write complex lighting algorithms from scratch. Once integrated, the API's data can be used to adjust the lighting of virtual objects in real-time, based on changes in the lighting conditions of the real-world environment.

7. Result and analysis :

The use of the Lighting Estimation API in AR experiences can significantly enhance the realism of virtual objects by rendering them in a way that matches the lighting conditions of the real-world environment. The results of implementing this approach using Unity Engine 2020.3.40f1, AR Foundation 4.2.7, and AR Core XR Plugin 4.2.7 have been promising.Another key concept is the idea of object-material interaction. In the real world, the way that objects are lit can affect how their materials appear. For example, a shiny object will reflect more light than a matte object, and objects in shadow will appear darker. The Lighting Estimation API takes into account these interactions by providing information about the direction and intensity of light sources in a scene, which can be used to accurately render virtual objects and their materials. The Lighting Estimation API provides detailed information about the lighting in a scene, which can be used to render virtual objects with shadows and reflections that match the real world. This helps to create a more immersive AR experience, as users can perceive that the virtual objects fit seamlessly into their environment.The use of transformation concepts such as rotation, uniform scaling, and shearing can further enhance the realism of virtual objects by enabling them to adjust to the orientation of the real-world environment. This integration of mathematical concepts and AR technology can lead to a more realistic and engaging AR experience for users. Overall, the Lighting Estimation API is an important tool for creating realistic AR/VR experiences

8. Conclusion:

In conclusion, the use of Lighting Estimation API in AR/VR technology has greatly improved the realism of virtual objects and their integration into real-world environments. By analyzing the lighting cues in a scene, the API provides detailed data that allows for the rendering of virtual objects under the same lighting conditions as their surroundings. This has resulted in a more grounded and engaging AR/VR experience for users, as virtual objects now seamlessly blend into the real world.Atlas
the Lighting Estimation API has proven to be a valuable tool in the development of AR/VR technology, and its integration with other software and mathematical concepts has only further enhanced its capabilities.

9. REFERENCES :

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