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# Real-time adaptable and coherent rendering for outdoor augmented reality

Sanghyun Seo<sup>1</sup>, Dongwann Kang<sup>2</sup> and Sangoh Park<sup>3\*</sup>

## Abstract

This paper describes the development and evaluation of a color estimation method that is able to create more natural lighting conditions for outdoor-purposed augmented reality (AR) technology. In outdoor AR systems, the real outdoor light source (i.e., the sun) illuminates real objects, while a virtual light source illuminates the augmented virtual objects. These two light sources result in color differentials, with the real object and virtual object being visualized as a mixture of the colors induced by the two light sources. As such, there is a visible difference in color between the real object and the virtual object. Consequently, this visible color difference will vitiate the sense of immersion felt by the AR user. Thus, to overcome this problem, we have defined each RGB color channel value by analyzing the color generated by the outdoor light source and applied the defined values to the virtual light source to reduce the visibility of the color differential between the two light sources, thereby reducing the visualized incompatibility between the virtual object and the real background. In addition, using virtual objects to express weather events, in combination with the color estimation method, we were able to demonstrate that the proposed method can adequately adapt to and manage the weather changes that affect outdoor AR. The proposed method has the potential to improve the visual coincidence between the real outdoor background and virtual objects.

**Keywords:** Augmented reality, Color temperature, Outdoor lighting, Real weather

## 1 Background

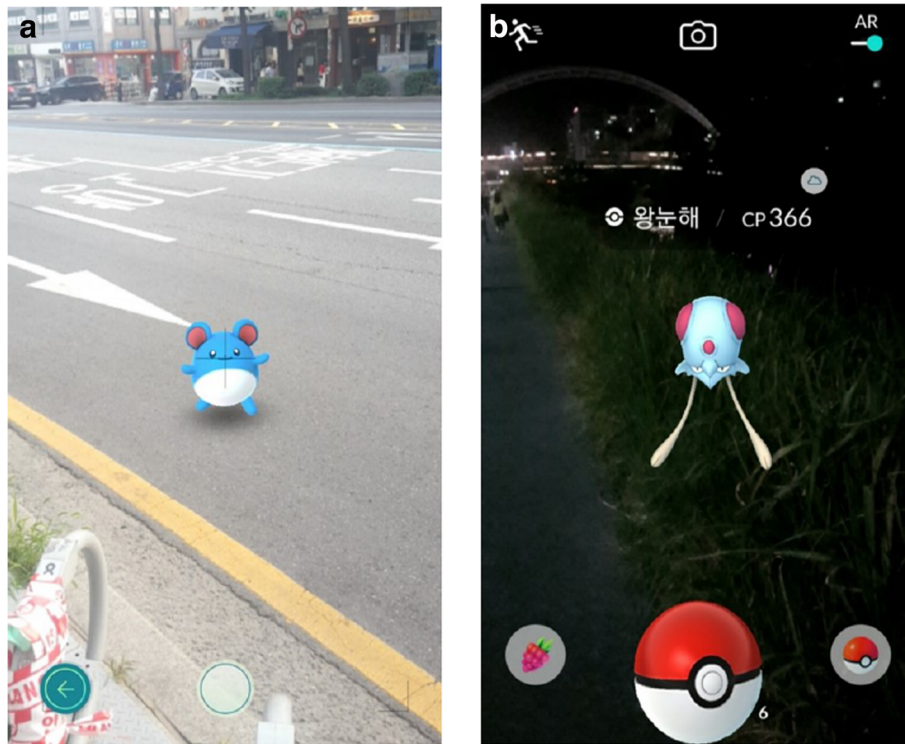
Recently, with the rapid development and diffusion of information technology and mobile-device-related technology within South Korea, approximately 80% of the population have come to own a personal mobile device that is equipped with a camera [1]. The rapid increase in the number of South Koreans who own a mobile device has created the opportunity for many people to use augmented reality (AR) technology without space constraints. For example, AR has become popularized with the recent release of *Pokemon Go*; in addition, the Gartner group has tracked AR trends for a number of years and used their findings to predict the prospects of future AR technology [2].

However, despite the increased interest, AR still has many obstacles to overcome, particularly with respect to information design, interaction methods, and equipment and ergonomics problems [3].

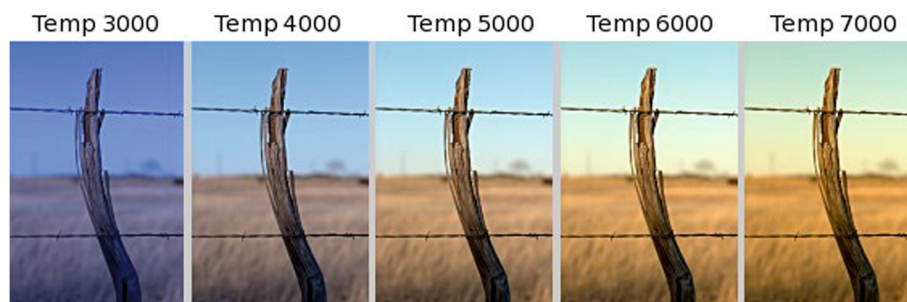
Information design incorporates a technique to determine the rendering style of a virtual object as based on various conditions of the real background viewed by a user. This synchronization technique is performed by altering the rendering style of the virtual object. The realization of the virtual object as a result of changing the rendering style amplifies the feeling of immersion experienced by the user and strengthens the power of information transfer. Because of these benefits, synchronization technology research is considered as necessary to ensure that users continue to use the content; this is especially relevant for outdoor use AR applications. Despite this reality, AR research is currently focused more on content diversity and methods to provide information than the application of synchronization technology. As an example, *Pokemon Go* does not incorporate synchronization technology; thus, the rendering style of the augmented character is unchanged, even under the condition of significantly different background lighting conditions (Fig. 1a, b). As can be ascertained from the screenshot presented as Fig. 1b, the

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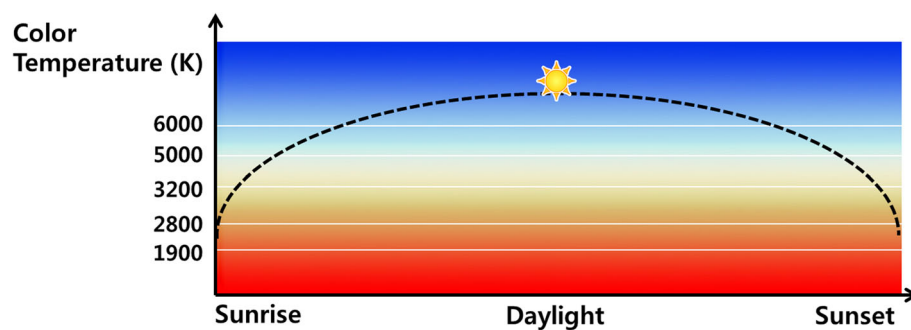
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**Fig. 1** Screenshots of Pokemon Go played at different times throughout the day: **a** 2 PM and **b** 8 PM



**Fig. 2** White balance according to color temperature



**Fig. 3** Color temperature variation throughout a single day

**Table 1** Algorithm pseudo-code [13]

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Temperature : Color temperature
Red, Green, Blue : The color value of each property
Set Temperature = Temperature \100

Calculate Red:
If Temperature <= 66 Then Red = 255
Else Red = Temperature - 60
Red = 329.698727446 * (Red^-0.1332047592)
If Red <0 Then Red = 0
If Red >255 Then Red = 255
End If

Calculate Green:
If Temperature <= 66 Then Green = Temperature
Green = 99.4708025861 * Ln(Green)-161.1195681661
If Green <0 Then Green = 0
If Green >255 Then Green = 255
Else Green = Temperature - 60
Green = 288.1221695283 * (Green ^-0.0755148492)
If Green <0 Then Green = 0
If Green >255 Then Green = 255
End If

Calculate Blue:
If Temperature >= 66 Then Blue = 255
Else
If Temperature <= 19 Then Blue = 0
Else Blue = Temperature - 10
Blue = 138.5177312231 * Ln(Blue) - 305.0447927307
If Blue <0 Then Blue = 0
If Blue >255 Then Blue = 255
End If
End If

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sense of immersion experienced by the user can be viti-  
ated by the incompatible rendering of the augmented  
character.

Thus, in this study, we investigated and explored the  
implementation of synchronization technology in AR by  
developing a synchronization method that uses color  
and weather information to adjust the lighting of vir-  
tual objects and thereby solve the problem demonstrated  
in Fig. 1. We also developed and tested algorithms that  
can be applied in real time in order to evaluate their  
practicability in real-time outdoor-based game platform  
applications. More specifically, we developed a synchro-  
nization method that reduces the heterogeneity between  
virtual objects and the real world in an AR field and  
includes processes such as camera filtering and rendering  
style conversion

### 1.1 Virtual object rendering by using direct lighting

Realizing the realistic lighting of a virtual object placed in  
a real scene is a high-priority goal of AR systems. How-  
ever, most existing approaches require the installation of  
additional equipment. Debevec proposed a method to cal-  
culate realistic lighting values as based on the conditions  
of scenes and their surroundings as observed through a  
fish-eye lens mounted onto a camera [4]. In AR, a fish-eye  
lens camera is commonly used to focus the light source  
onto the surrounding environment [5]. However, because  
fish-eye lenses are not commercially available for mobile  
devices, at present, a method that incorporates them is not  
applicable to mobile devices. Furthermore, although this  
method can quantify the light source position and shadow  
of a virtual object, it does not consider the attributes of the  
colors contributing to the background lighting.

### 1.2 Realistic virtual object creation in a real outdoor environment

Kolivand and Sunar developed a technique to describe  
the interaction between the colors in the sky and vir-  
tual objects in AR technology with shadows. In addi-  
tion to more realistic shadow projection, they focused  
on the projection of realistic virtual objects in an out-  
door AR environment [6]. Kolivand and Sunar's aim is  
similar to that of the study presented in this paper, as  
this study aims to increase the compatibility of virtual  
objects with the physical environment by determining  
the position of the sun with respect to the latitude,  
date, and time. In addition, in this study, the posi-  
tion and quality of shadows were determined by using  
a new algorithm, Z-GaF Shadow Maps, and the back-  
ground illumination was set by using the ambient light of  
the skybox.

### 1.3 Utilizing natural environmental lighting in AR

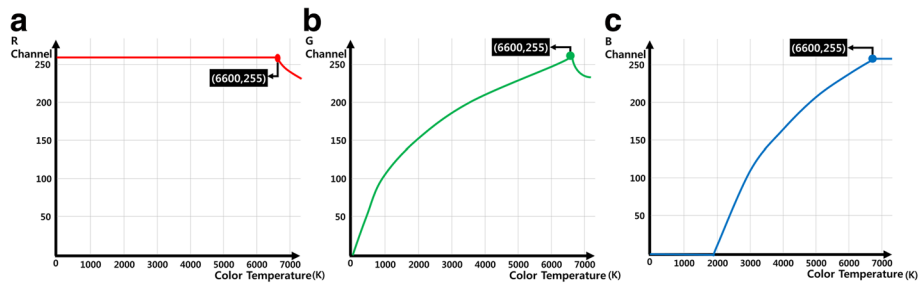
Rohmer et al. used a mobile device with a depth sen-  
sor to implement a white balance-based color correction  
method. Their method was demonstrated to yield more  
photorealistic renderings as a result of utilizing the vari-  
ants of differential light simulation techniques. Addition-  
ally, the proposed method was tailored to mobile devices  
and operated under the condition of an interactive frame  
rate [7]. Although their use of white balance is differ-  
ent from that applied in the method described in this  
paper, their results suggest that real-time photorealistic  
rendering can be achieved by considering the white  
balance.

## 2 Methods

### 2.1 Real-time color lighting representation technology for outdoor AR

#### 2.1.1 Role of color lighting

The representative features of lighting include intensity,



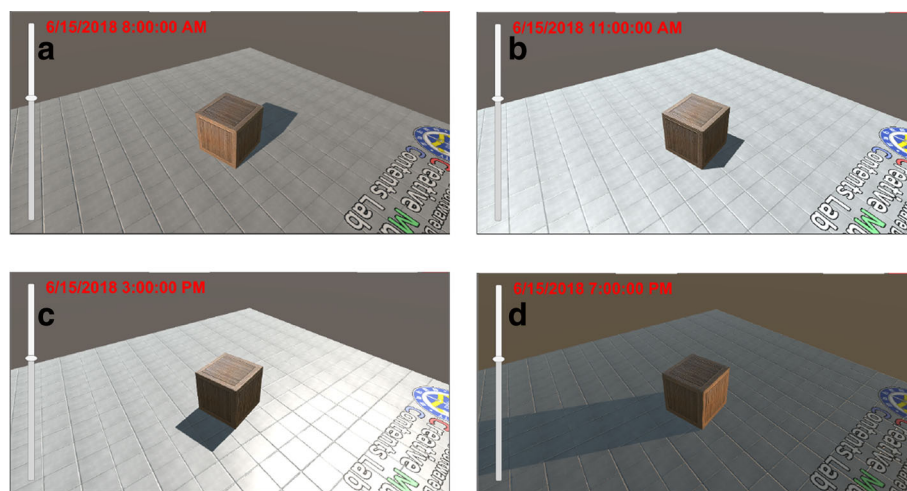
**Fig. 4** Graph of RGB channel values according to color temperature : **a** R channel, **b** G channel, and **c** B channel

position, and color. Among these features, color significantly influences the ability of a system to perform human cognitive function (accuracy, reactivity, attention, etc.) recognition and time-lapse recognition [8, 9]. Furthermore, color temperature and color rendering are known to be the main factors affecting the color judgment of the user. Thus, the factors that affect lighting have the ability to induce a metamerism error, which could result in the same color being recognized as different colors or different colors being recognized as the same color [10]. This type of error phenomenon can be easily observed in outdoor environments, as numerous factors affect the perceived color of sunlight. As the sun appears to move across the horizon, the period of sunrise and sunset tends to correspond to a mixture of colors that is perceived as orange light, whereas noon-day tends to correspond to a mixture of colors that is perceived as blue light. Therefore, if the color emitted by the source of illumination does not change over time, the perceived heterogeneity between the actual background and the virtual object can become increasingly apparent.

### 2.1.2 Color temperature definition

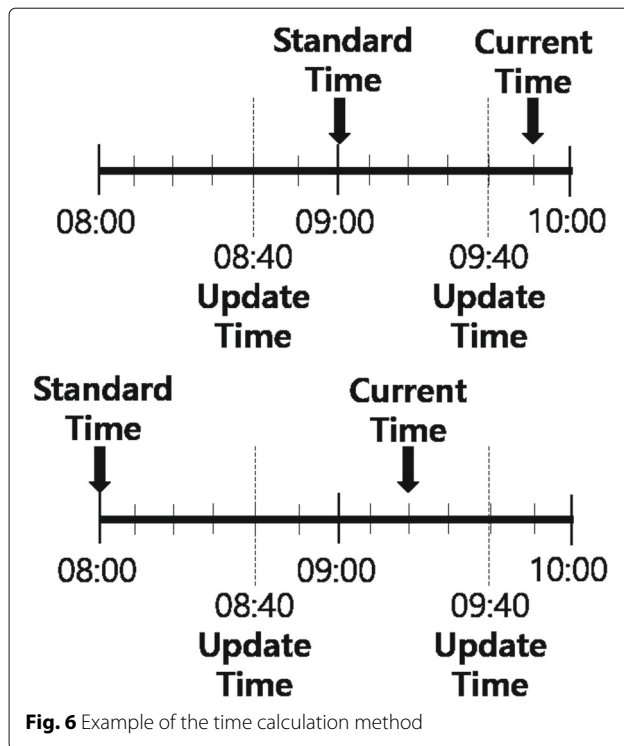
Color temperature refers to the temperature of a black-body radiator that emits light that is similar in color to that of the light source. A black body is an object that completely absorbs all of the radiant energy incident on the surface. As the black body is heated, its color changes to red, white, and blue. If the color temperature of the light source does not exactly match that of the black-body radiator, the color temperature with the closest value, i.e., the correlated color temperature (CCT), can be used; since the colors of the black-body radiator and light source never exactly match, CCT is used to represent the color temperature. Kelvin (K) is the unit used to express the color temperature [11]. In photography, color temperature is used to adjust the white balance, which is purposed to correct the color distortions observed as a result of taking pictures in an environment with natural or artificial lighting.

Figure 2 shows how outdoor photographs can be corrected by using white balance; it can be seen that the overall lighting differs according to the temperature. Considering this, the rendering style of an augmented virtual



**Fig. 5** Application of color temperature to game engine environment. **a** AM 08:00. **b** AM 11:00. **c** PM 03:00. **d** PM 07:00





object can be corrected by applying the color temperature used in white balancing to determine the virtual lighting. Because this study is focused on the development of a technique that can be used to create more natural lighting, we have decided to apply the color temperature of the sun, which is the representative outdoor light source. During sunrise and sunset, the sun produces low-intensity lighting with a low color temperature of 2500 to 3500 K; in contrast, at noon, the sun produces white high-intensity lighting with a color temperature that ranges from 4000 to 7000 K [12]. Thus, the lowest temperature of 2500 K was implemented as the sunrise and sunset color temperature, and the maximum temperature of 7000 K was implemented as the noon color temperature.

**Table 2** Item names according to tags

Tag name	Item name	Unit	Tag name	Item name	Unit
T1H	Temperature	°C	REH	Humidity	%
RN1	1-h precipitation	mm	PTY	Precipitation type	Code value
SKY	Sky status	Code value	LGT	Thunderstroke	Code value
UUU	East-west wind component	m/s	VEC	Wind direction	°
VVV	North-south wind component	m/s	WSD	Wind speed	m/s

After establishing the color temperature for these three events, the color temperature between sunrise/sunset and noon changes linearly according to the altitude of the sun, as is shown in Fig. 3.

### 2.1.3 Color temperature algorithm

In the previous section, we described how the color temperatures of sunrise/sunset and noon were determined. In this section, we explain why the lighting color should be expressed as based on the color temperature. In order to use the color temperature to determine the lighting color, the RGB values must be determined. In this study, the RGB values were determined by using a temperature-to-RGB conversion algorithm designed by Helland [13]; the pseudo-code is provided in Table 1.

Figure 4 shows the graph for each RGB attribute value as a function of the color temperature. In each graph, the color temperature of 6600 K and color value of 255 are marked; for all three color channels, it can be seen that the relationship between the color channel and color temperature sharply changes at 6600 K.

Table 1 shows the derivation of the pseudo-code using the graph. Table 1 provides a high approximation, and real-time operation is possible. However, it is not sufficient for use in the scientific field.

Figure 5 illustrates the application of the color temperature algorithm to a game engine. Orange light can be observed in Fig. 5a, d, as the time of day corresponds to sunrise and sunset, respectively; conversely, white light can be observed in Fig. 5b, c, corresponding to approximately noontime.

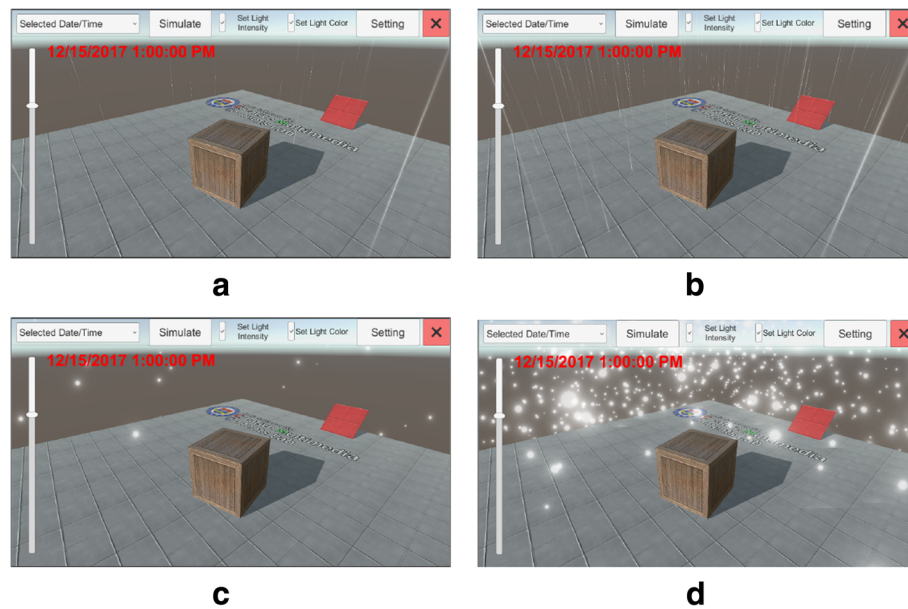
## 2.2 Weather expression in outdoor-purposed AR

### 2.2.1 AR and weather

Abrupt changes in weather are frequent and highly visible and affect environmental objects such as trees. These weather features interfere with enhancing environmental awareness by dynamically overlapping virtual objects and the actual environment which are the characteristics of AR [14]. In this study, we attempted to solve this visualization interference problem by expressing weather as virtual objects.

### 2.2.2 Parsing weather information from open API service

The Korea Meteorological Administration weather change information application programming interface (API) was used to obtain URL-formatted weather data from a domestic weather forecast site. The time had to be entered into the API in the URL format; an example of the calculation method is presented in Fig. 6, which shows that the reference time (input time) changes



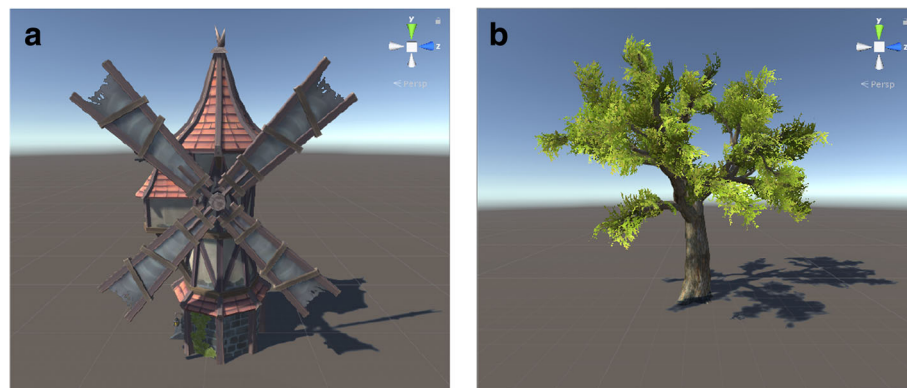
**Fig. 7** Examples of snow and rain implemented in the game engine: **a** minimum rain setting, **b** maximum rain setting, **c** minimum snow setting, and **d** minimum snow setting

every 40 min past the hour. For example, 09:00 is used for the period of 09:41–10:39. This means that the weather information can have a time delay of 40 min to 1 h and 39 min.

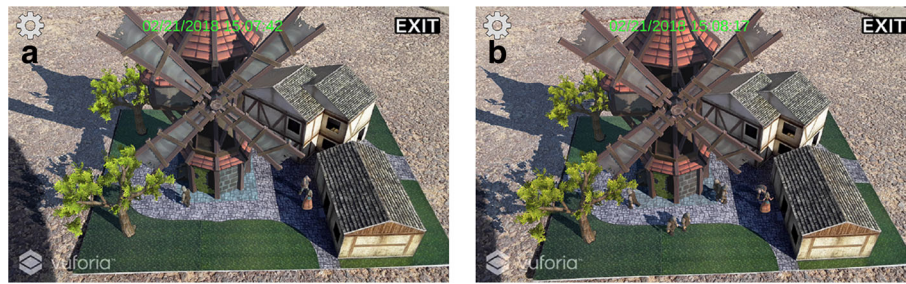
Time was input into the API in URL format, and weather information classified by specific tags was output in the XML format. Note that, via this interface, the user is only able to obtain the desired attributes through parsing. Additionally, the AR-based weather effects implemented in this study were limited to rain, snow, and wind, as only precipitation type, wind direction, and wind velocity information were parsed shown in Table 2.

### 3 Results and discussion

Figure 7 shows how snow and rain were visualized by the game engine. The proposed method offers flexibility by allowing the user to control the amount of snow and rain. However, because the expression of wind is not as visible as that of snow or rain, it was indirectly expressed via a virtual object, as is shown in Fig. 8. Figure 9 presents an example of the effects of color temperature application in an AR environment. The representative time of day was at sunset when the color change would be noticeable. As can be seen, the blades of the virtual windmill in Fig. 9b have more of an orange hue than those of the virtual windmill in Fig. 9a. Furthermore, as can also be observed in Fig. 9b,



**Fig. 8** Virtual objects used to indirectly express wind effects: **a** windmill and **b** tree



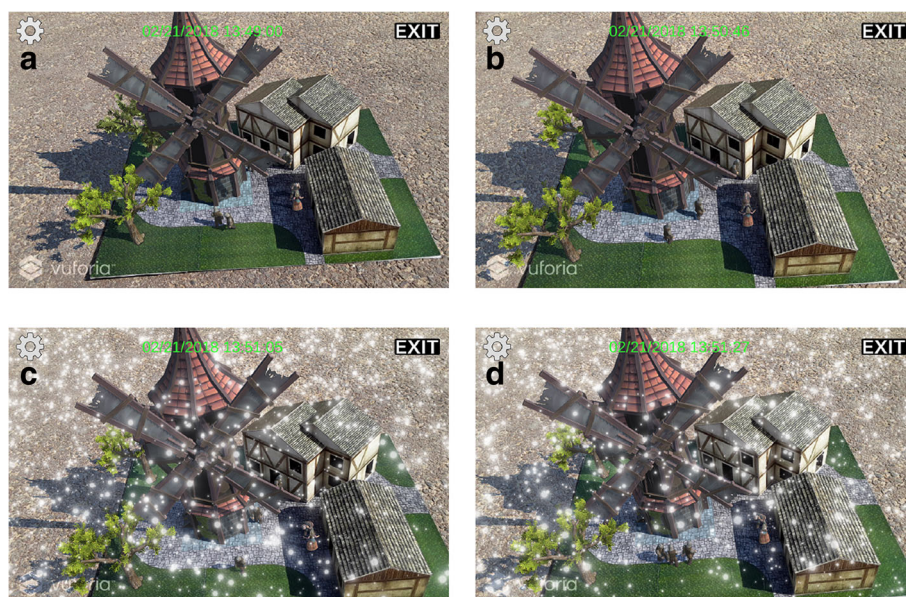
**Fig. 9** Example of color temperature application in an AR environment: **a** no effect and **b** effects of color temperature applications

application of color temperature to the virtual object makes it much more difficult to distinguish as a non-real object, as its color is consistent with that of the real object, i.e., the house. Figure 10 shows that the virtual weather objects can be easily integrated into a real environment and have the benefit of flexibility. Thus, because, unlike the background lighting, weather events can be dynamically expressed in the AR environment, a realistic time flow can be applied. This verifies the ability of the synchronization technology to effectively represent weather events.

#### 4 Conclusions

In this paper, we proposed a method to solve the visualization incompatibility problem in AR by altering the rendering style of virtual objects as based on real outdoor lighting color data and real weather

attributes. As previously mentioned, we focused on outdoor-purposed AR because changes to the real background are diverse and extensive. Consequently, the lighting color and weather event settings were able to be expressed in real time, as demonstrated by implementing the method in a game engine. Moreover, since the proposed method was developed for application in a game engine, it can be immediately integrated into other game engines. Furthermore, the results presented here suggest that the use of real data can reduce the visualization disparity between virtual objects and real background scenes. Thus, further research is necessary to evaluate the adaptability of this technique and confirm that the results can be replicated in an actual outdoor AR environment. In the future, we plan to improve the realism of lighting color and to diversify weather expression.



**Fig. 10** Example of weather expression in an AR environment: **a** no weather event, **b** rain, **c** snow, and **d** rain and snow



## Abbreviations

API: Application programming interface; AR: Augmented reality; CCT: Correlated color temperature; URL: Uniform resource locator; XML: eXtensible markup language

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## Availability of data and materials

The data used and/or analyzed during the current study are available from the authors on reasonable request.

## Authors' contributions

All authors take part in the discussion of the work described in this paper. SHS proposed the framework of this work and initiated the main algorithm of this work. DWK and SOP carried out the whole experiments and drafted the manuscript. All authors read and approved the final manuscript.

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Sanghyun Seo received his B.S. degrees in Computer Science and Engineering from Chung-Ang University, Seoul, Korea, in 1998 and M.S. and Ph.D. degrees in GSAIM Dep. at Chung-Ang University, Seoul, Korea, in 2000 and 2010. He was a senior researcher at G-Inno System from 2002 to 2005. He was the postdoctoral researcher at Chung-Ang University, in 2010, and the postdoctoral researcher at LIRIS Lab, Lyon 1 University from February 2011 to February 2013. He had worked at the ETRI (Electronics and Telecommunications Research Institute), Daejeon, Korea, May 2013 to February 2016. Now, he is currently a faculty of the Department of Media Software at Sungkyul University. He has been a reviewer in Multimedia Tools and Applications (MTAP), Computer and Graphics UK (Elsevier), Journal of Supercomputing (IOS), Visual Computer (Springer), and Program Committee member in many international conferences and workshops and has edited a number of international journal special issues as a guest editor, such as Journal of Real-Time Image Processing and Journal of Internet Technology, and Multimedia Tools and Applications. He has been appointed as an Associate-Editor of the Journal of Real-Time Image Processing since 2017. His research interests are in the area of computer graphics, non-photorealistic rendering and animation, 3D GIS system, and real-time rendering using GPU, VR/AR, and game technology. Dongwann Kang is an Assistant Professor in the Department of Computer Science and Engineering at Seoul National University of Science and Technology. He received his Ph.D. from Chung-Ang University in Korea in 2013, where he was a research fellow until Jun 2015. He was a lecturer of Undergraduate Interdisciplinary Program in Computational Sciences, Seoul National University, Korea (from Mar 2014 to Jun 2015); a lecturer at the Department of Multimedia, Sookmyung Women's University, Korea (from Mar 2014 to Dec 2014); and a visiting researcher (from Jul 2015 to Jan 2018) and a Marie Skłodowska-Curie fellow (from Feb 2018 to Aug 2018) at the Faculty of Science and Technology, Bournemouth University, UK. His research interests include non-photorealistic rendering and animation, emotional computing, image manipulation, and GPU processing. Sangoh Park received B.S., M.S., and Ph.D. degrees from the School of Computer Science and Engineering at Chung-Ang University, in 2005, 2007, and 2010, respectively. He has been serving as an Assistant Professor of the School of Computer Science and Engineering at Chung-Ang University since 2017. He served as a Senior Researcher of Global Science experimental Data hub Center at Korea Institute of Science and Technology Information from 2012 to 2017 and a Research Professor at the School of Computer Science and Engineering. His research interests include high-performance computing, big data system, tape storage system, embedded system, cyber physical system, home network, smart factory, and linux system.

## Competing interests

The authors declare that they have no competing interests.

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