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Visualization Method of Heat Risk through Light Environment Reproduction Considering Cloud Coverage

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Abstract. In recent years, the number of heatstroke patients in Japan has been increasing, necessitating public awareness and precautions. While the Ministry of the Environment provides heat index information for urban area scales online, there are no means to obtain localized heat index data. Previous studies have visualized the heat index of varying heat environments using game engines based on public 3D data and meteorological information by rendering sunlight and shadows as computer graphics (CG). However, the applicability is limited to clear weather conditions. This study focuses on the fact that heat stress on the human body depends not only on solar radiation but also on meteorological factors such as humidity and that the risk of heatstroke is not necessarily higher only under clear weather. We develop a model to estimate cloud cover parameters from observed meteorological elements. By generating cloud cover within the game engine according to the weather conditions, we reproduce the celestial light environment and expand the applicability of heat risk visualization.

1 Introduction

In recent years, the number of heatstroke patients and fatalities has been on the rise due to climate change, and this is becoming a major social issue [1]. Although heatstroke is a life-threatening condition, it can be prevented if individuals are aware of the risk of occurrence and take preventive measures [2]. Wet Bulb Globe Temperature (WBGT), a heat environment index, is widely used as an indicator for preventing heat stroke. The U.S. military initially uses WBGT to prevent heatstroke during exercises. It has been standardized in ISO 7243 (JIS Z 8504) and is recognized as a guideline for both occupational and daily environments [3-5]. The Ministry of the Environment of Japan provides WBGT values on the Web to raise awareness of heat stroke prevention [6]. However, because the values are for urban areas and are updated hourly, they are not easily recognized as risks in the environment around us.

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Facility and site managers need to understand the environmental risks visitors and workers face. Since the number of WBGT sensors that can be deployed to collect information over a wide area is limited, managers often rely on personal experience to make action decisions at each site. Furthermore, heat stress on the human body results not only from apparent solar radiation, but also from invisible humidity and other weather factors. Thus, heatstroke can occur even in non-clear weather conditions. It is worth noting that the previous WBGT estimation techniques for outdoor environments have factored in shadows caused by sunlight, but their applicability has been limited to clear skies.

This study focuses on the fact that the risk of heatstroke is not necessarily higher only during clear weather. By creating a model to determine cloud cover parameters based on observed meteorological elements, we propose a method to estimate and visualize the distribution of the heat index under various weather conditions.

2 Previous Research

The WBGT index is calculated based on the relationships between air temperature, humidity, and radiant heat, but measuring radiant heat requires a black globe thermometer. Okada et al. estimated the black globe temperature using explanatory variables such as total solar radiation, wind speed, and dry bulb temperature [7]. Yasumuro et al. found a correlation between pixel values in photographs taken on a standard reflector plate and total solar radiation, replacing photographic images with CG generated by global illumination (GI) to determine total solar radiation for each pixel and estimated WBGT using the method of Okada et al. [8]. Furthermore, Sumida et al. accelerated the generation of solar radiation CG using a game engine with real-time GI, developing a system to acquire basic meteorological information in real-time. They proposed a method to visualize heat index distribution under varying sunlight conditions and stream it to general users on the web, demonstrating the effectiveness of its functionality [9].

GI is a CG technology that optically and physically handles the global transport of light energy, allowing for the simulation of solar radiation conditions, including vegetation and buildings [10]. However, the primary environment within the game engine is limited to clear weather, making it challenging to represent changes in sunlight conditions due to light scattering by clouds. This limitation hinders addressing heatstroke risks that can occur even under cloudy conditions.

3 Proposed Method

This study aims to address the limitations of previous research by generating clouds within the game engine's sky environment to estimate the heat index under various sky conditions, including cloudy weather.

The primary factor affecting the total solar radiation reaching the ground under clear skies is the amount of direct solar radiation from the entire sky. Under cloudy skies, the path of light reaching the ground becomes more complex due to transmission and scattering by clouds. For simplicity, we use two parameters in the game engine's skylight settings: Cloud Coverage (CC), representing the proportion of the sky covered by clouds, and Layer Height Scale (LHS), representing the thickness of the cloud layer. We can estimate the solar radiation reaching the ground using limited meteorological information by setting these two parameters to reproduce the solar radiation at the ground level under observed meteorological conditions. This estimation process can be linked to the existing methods for estimating black globe temperature and WBGT.

Determining these parameters involves using a regression model with CC derived from cloud cover values and LHS from basic meteorological information, using solar radiation as the output value. Pre-determined values corresponding to the estimated solar radiation are then set (Figure 1).

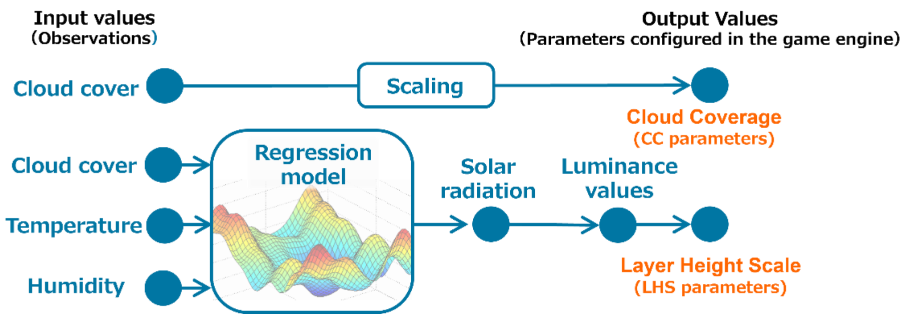

Fig. 1. Data flow of the cloud parameter determination model.

The proposed processing flow is shown in Figure 2. The user inputs the desired date, time, and location to determine the heat risk. The system retrieves corresponding 3D data from a 3D data server and basic meteorological information from a weather server. The ground-level solar radiation is estimated through the regression model, setting the cloud parameters to represent the estimated solar radiation conditions. A WBGT-based heatmap image is then generated based on the real-time rendering of the shade distribution based on obtained air temperature (dry bulb temperature), humidity (wet bulb temperature), and wind speed. Color transformation is applied using UV coordinates created based on WBGT risk level color indicators as shown in Figure 3.

The meteorological data server is a robust source, containing forecast data provided by the Japan Meteorological Agency and locally measured data from sensors. Similarly, the 3D data server is a reliable repository containing 3D data corresponding to urban areas published by the Geospatial Information Authority of Japan and 3D data acquired through scanning. This process ensures users can confidently view the distribution of the heat index under various sky conditions by simply inputting the date, time, and location.

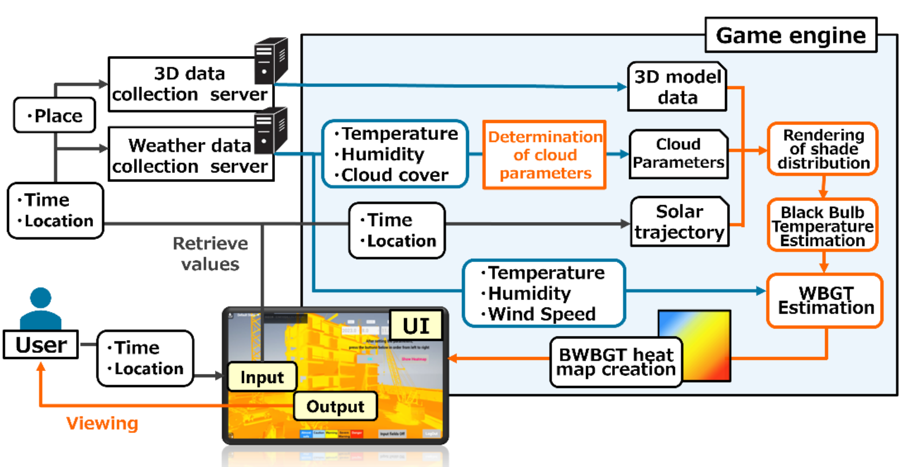

Fig. 2. Flowchart of the proposed method.

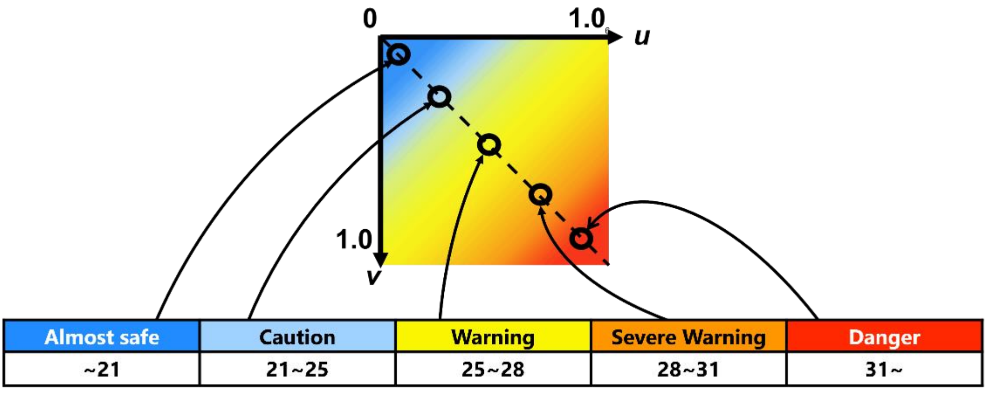

Fig. 3. U-V coordinate of the color texture based on Ministry of the Environment guidelines.

4 Implementation and Verification

4.1 Construction of the Regression Model

In this study, we constructed a regression model to estimate solar radiation by measuring meteorological data in Suita City from late June to late September. We measured dry bulb temperature, wet bulb temperature, humidity, solar radiation, illuminance, wind speed, and cloud cover, resulting in 102 data points. For constructing the regression model, we used temperature, humidity, and cloud cover as explanatory variables, which showed a correlation with solar radiation and are easily accessible from public information. Solar radiation was set as the target variable. We compared models built using linear regression, regression trees, support vector machines (SVM), Gaussian process regression, kernel ridge regression, and neural networks. The Gaussian process regression model was selected for its high accuracy and suitability for small datasets [11]. Unlike other methods, Gaussian process regression provides a distribution of functions, allowing us to express estimation uncertainty. As shown in Figure 4, the model achieved an RMSE (Root Mean Squared Error) of 207.8 and a coefficient of determination R^2 of 0.55.

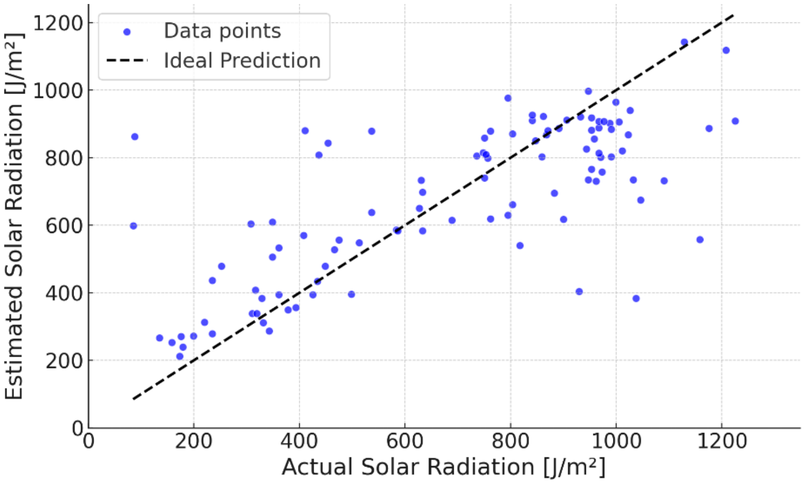

Fig. 4. Accuracy of the regression model.

4.2 Visualization of Heat Risk

We used Unreal Engine 5 (UE) as the game engine capable of real-time GI rendering. We set the maximum illuminance (lux) of sunlight in UE. We used a 3D model with surface reflection characteristics equivalent to a standard diffuse reflector plate to render the sunlight conditions. We used the Ultra Dynamic Sky library (UDS) to configure detailed cloud settings in UE. By specifying the date, time, and latitude/longitude of the region and setting cloud parameters from publicly available meteorological information, we could normalize CC (cloud coverage) from 0 to 2.2 and adjust LHS (layer height scale) according to the estimated solar radiation derived from the regression model and allowed us to replicate non-clear sky conditions. Based on the above procedure, similar to the method of Sumida et al., we estimated WBGT for each pixel of the CG and displayed the surrounding heat risk using a heat map texture, as shown in Figure 5. The figure shows the heatstroke risk distribution under increased cloud cover and lower shadow contrast conditions.

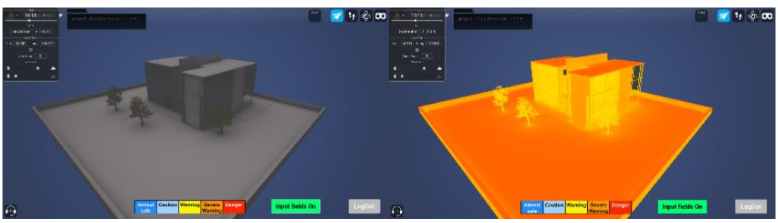

Fig. 5. Visualization of WBGT.

4.3 Comparative Verification with Previous Research

We compared the accuracy of WBGT estimation under cloudy conditions using our method and the method of Sumida et al. We conducted two pattern comparisons of WBGT values estimated by heatmap images created with each method and the actual measured WBGT values for a free 3D model of a building. Measurements were taken at the Sumida of a plaza, so in the game engine, we also compared WBGT values at locations unaffected by building shadows. As shown in Figures 6 and 7, the method of Sumida et al. did not account for light scattering due to cloud cover, resulting in significant errors of 3.4°C and 3.7°C. In contrast, our method showed more minor errors of 1.2°C and 1.0°C, demonstrating improved accuracy.

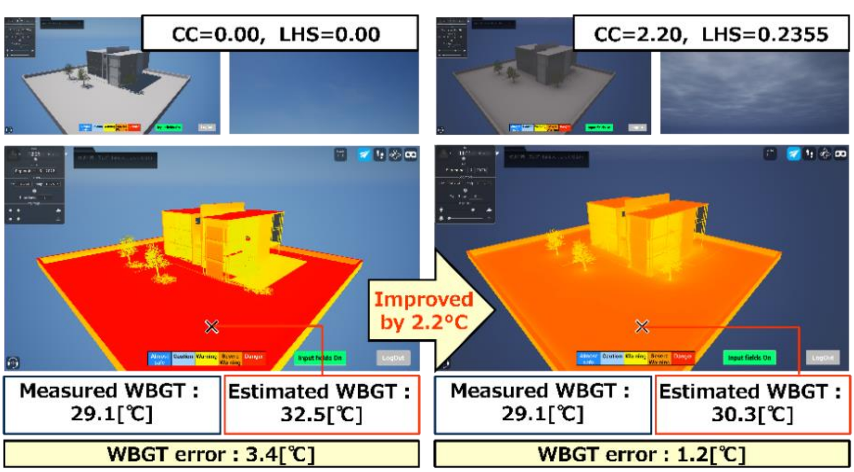

Fig. 6. Accuracy comparison with previous research (1).

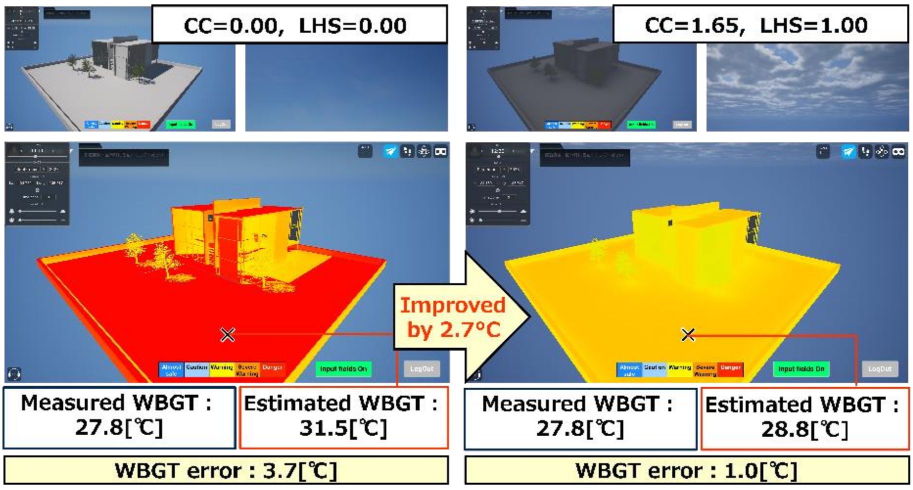

Fig. 7. Accuracy comparison with previous research (2).

5 Application Example of the System

Figure 8 shows an example of applying this system to a virtual construction site 3D model. By simulating the solar altitude, the system can visualize and track the changes in the heat index distribution over time. Utilizing weather forecast data obtained through the OpenWeatherMap API provided by OpenWeather, as well as forecast data from the Japan Meteorological Agency, allows managers to preemptively grasp heat stress risks at work sites. With such a system's introduction, specific heat stroke countermeasures are expected to be implemented so that workers can be adequately prepared to protect their health.

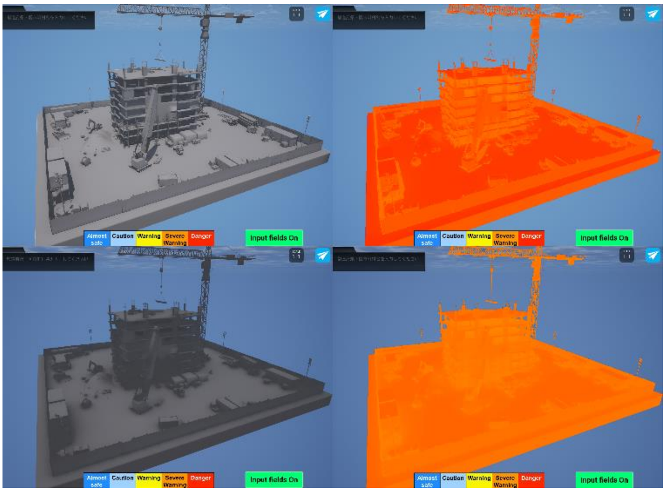

Fig. 8. Application example of the system in a virtual construction site.

6 Conclusion

In this study, we constructed a model to determine cloud cover settings within a game engine based on limited meteorological information, allowing us to estimate heat index distribution under various sky conditions by reproducing the celestial light environment. We verified the system's accuracy by comparing the estimated WBGT with the measured WBGT. The results showed an overall error range of approximately -0.05°C to 2.79°C, with an average overestimation of 1.4°C. Although the values indicating the danger of the heat environment leaned towards safety, the stability of the estimation was low, highlighting the need to improve the accuracy of the regression model.

The primary reasons for the reduced accuracy were identified as the instantaneous nature of all the measured data and the insufficiency of the data. Moving forward, instead of using instantaneous values for the meteorological data used in this paper, we will improve the regression model and resolve the lack of data by collecting data that considers temporal variability. In addition, since the characteristics of 3D models of geological objects (e.g., transparency of leaves) are not currently considered, we plan to refine these parameters by using actual measurements.

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References

1. Nakamura, S., Kusaka, H., Sato, R., & Sato, T. (2022). Heatstroke risk projection in Japan under current and near future climates. Journal of the Meteorological Society of Japan, 100(4), pp. 597-615. https://doi.org/10.2151/jmsj.2022-030
2. Yaglow C, Minard D. Control of Heat Causalities at Military Training Centers. American Medical Association Archives of Industrial Health. 16: 302-316, 1957.
3. International Organization for Standardization. Ergonomics ofthe thermal environment — Assessment of heat stress using the WBGT (wet bulb globe temperature) index. ISO7243: 2017.
4. Japanese Industrial Standards: "Ergonomics of the thermal environment — Evaluation of heat stress using the WBGT (wet bulb globe temperature) index. JIS Z 8504: 2021".
5. Japanese Society of Biometeorology: "Guidelines for the Prevention of Heatstroke in Daily Life Ver.4": https://seikishou.jp/committee/, (getting 2024.5.19)
6. Ministry of the Environment, Labour and Welfare: Number of deaths due to heatstroke, Vital Statistics (finalized numbers), https://www.wbgt.env.go.jp/en/, (getting 2024.5.19)
7. M.Okada, M. Okada and H. Kusaka (2013). Wide-area application and parameter adjustment of the Okada-Hisaka black-bulb temperature estimation equation, Heat Island, Vol. 8, pp. 13-21. (In Japanese)
8. Y. Yasumuro, K. Ichihara, Y. Nishiura, D. Ikegawa, M. Hayashi and T. Ozaki (2018), Estimation of WBGT using 3DCG and its application, Journal of Civil Engineering G(Environment), Vol. 74, No. 6, pp. II-1-II-8. (In Japanese)
9. N. Sumida, T. Ozaki, S. Kubota, H. Dan, Y. Yasumuro (2022), Visualization of Environmental Heat Risks with Global Illumination in Game Engine, Proceedings of the 22nd International Conference on Construction Application of Virtual Reality (CONVR2022), pp. 677-683.
10. K. Kurachi (2007), CG Magic: Rendering, Ohmsha, 2007.
11. S.Akaho: "Basics of Gaussian Process Regression", Systems/Control/Information, Vol. 62, No. 10, pp. 390-395, 2018. (In Japanese)