Estimating urban thermal environments using UAV, micro climate modeling, AI[1)]

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Abstract: Currently, many urban areas around the world are suffering from summer heat waves, resulting in many casualties. In order to reduce the casualties caused by heat waves, it is necessary to quickly diagnose heat waves and devise effective countermeasures. It is also important to identify the actual thermal comfort that can be felt due to heat waves. However, there is a method that utilizes climate modeling to predict thermal comfort, but it takes a lot of time for simulation. Therefore, it is necessary to develop a technology that can quickly predict thermal comfort, and this study aimed to develop a thermal comfort prediction technology using drones and artificial intelligence. Multispectral images, surface temperature images, and sky view factor images were collected from drones, and a convolutional neural network (CNN) model was applied to develop a thermal comfort prediction model. As a result, the thermal comfort prediction accuracy was approximately 95% or higher. The results of this study are expected to play a significant role in reducing casualties by quickly identifying thermal comfort using drones in the event of a heat wave in the future and responding to areas vulnerable to heat waves.

1. Introduction

Due to global climate change, extreme weather phenomena such as heat waves and cold spells are occurring frequently. In particular, summer heat waves have caused many heat-related illnesses and have had a negative impact on society and the economy overall. In order to reduce human casualties caused by heat waves, it is important to establish rapid diagnosis and response measures. In addition, it is most important to understand the thermal comfort that people can actually feel.

There are currently methods for analyzing thermal comfort, such as field measurement and climate modeling. Field measurement has the advantage of being able to derive accurate thermal comfort values, but it has limitations in understanding the thermal comfort of areas other than the measurement point. Climate modeling can create a thermal comfort distribution map and make predictions based on time changes. However, it has the disadvantage of requiring a lot of simulation time. To complement the limitations of existing thermal comfort analysis, a method using drones is being applied. Drones have the advantage of being able to precisely analyze the physical environment of the ground surface and collect information through drone operation in a desired area and time. However, there are limitations in directly understanding the thermal comfort in the atmosphere. Therefore, it is necessary to develop a technology to predict thermal comfort using drones by supplementing it with field measurements and climate modeling data.

This study analyzed the characteristics of the physical and thermal environments using field measurements and climate modeling data to develop a technology to predict thermal comfort using drones. In addition, we attempted to develop a thermal comfort prediction model using a deep learning model by considering the variables of the drone's physical and thermal environments.

2. Method

The study sites of this study are part of the campus of Changwon National University and Yongji Park, an urban park located in Changwon City, southeastern South Korea (Figure 1).

This study is divided into three processes, as shown in Figure 2: 1) data collection, 2) development of a deep learning-based Tmrt prediction model, and finally 3) performance evaluation of the Tmrt prediction model based on UAV images.

UAV images were taken to collect data related to the physical and thermal environments. The physical environment is SVF and NDVI, and the thermal environment is LST. The data was collected by mounting the multispectral sensor MicaSense on the fixed-wing aircraft eBee, and the orthoimage was created using Pix4D Mapper software.

The ENVI-met modeling constructed input data using the UAV orthoimage. Then, the initial weather conditions were input and simulated by considering the same time as the UAV shooting time.

The field measurement measured radiant fluxes at the field measurement point in Figure 1 and calculated Tmrt. The development of a deep learning-based prediction model was targeted at the Changwon National University campus, site 1, and the Tmrt prediction model was developed using the CNN technique by setting the UAV's SVF, NDVI, and LST as input variables(Figure 3). The ratio of training data and test data was set to 7:3.

The Tmrt prediction model was applied to site 2, Yongji Park, and the accuracy of the prediction model was evaluated.

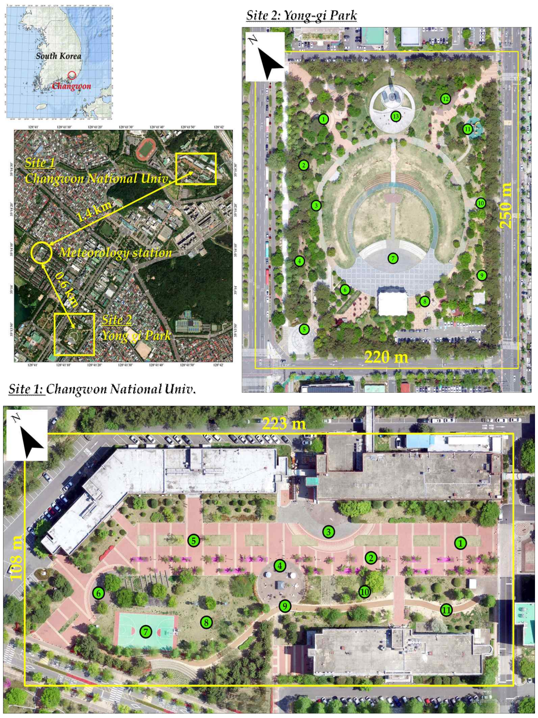

Figure 1. Study sites

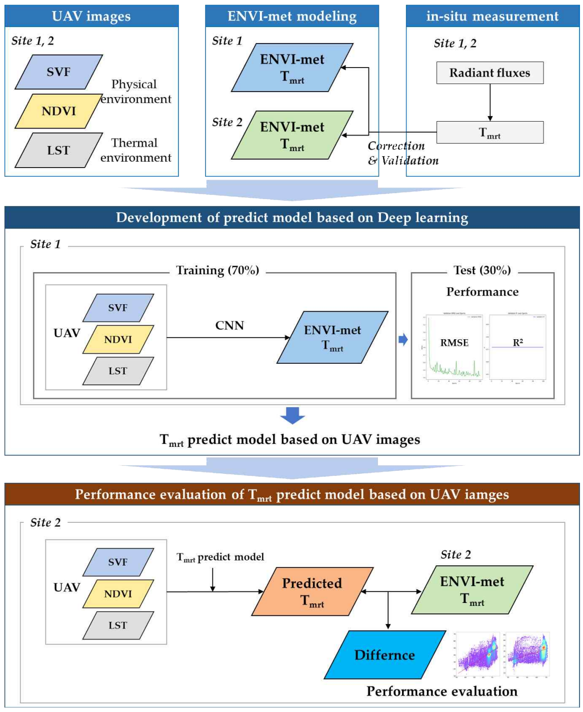

Figure 2. Research Framework

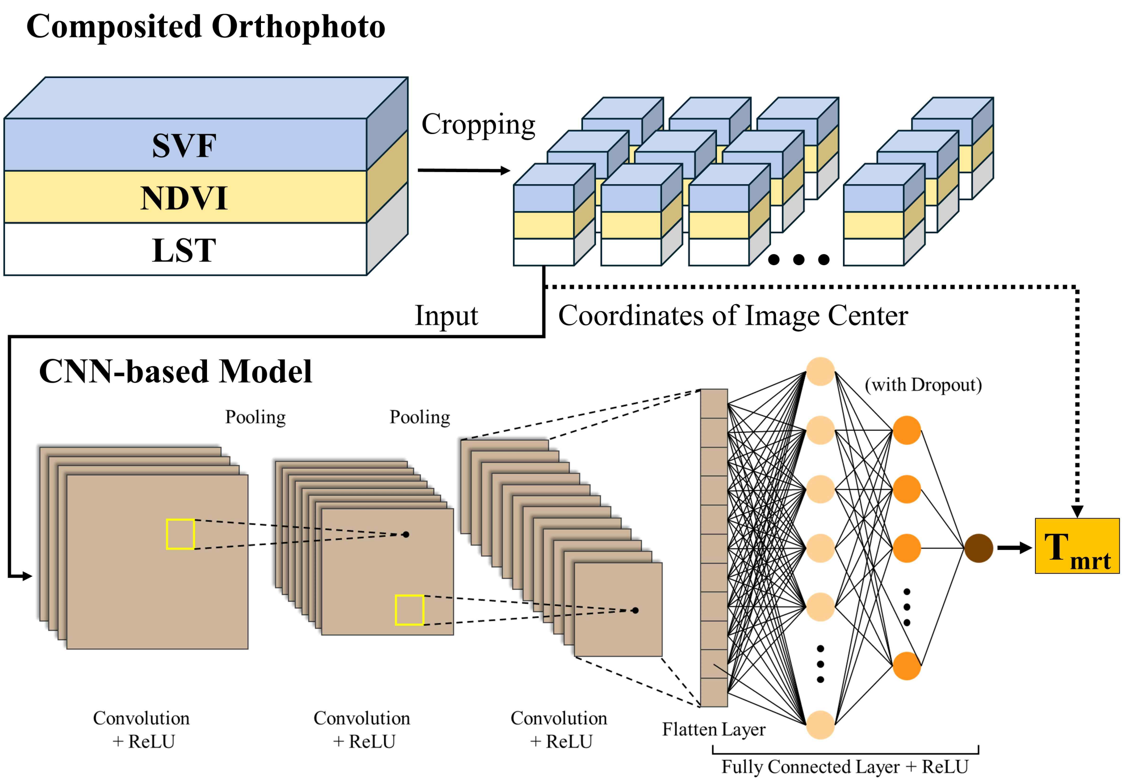

Figure 3. Construction of CNN model for estimating Tmrt using UAV SVF, NDVI, and LST

3. Results and discussion

The results of evaluating the performance of the CNN model show that as the number of iterations increases, the difference between the validation training data and the validation data decreases(Figure 4).

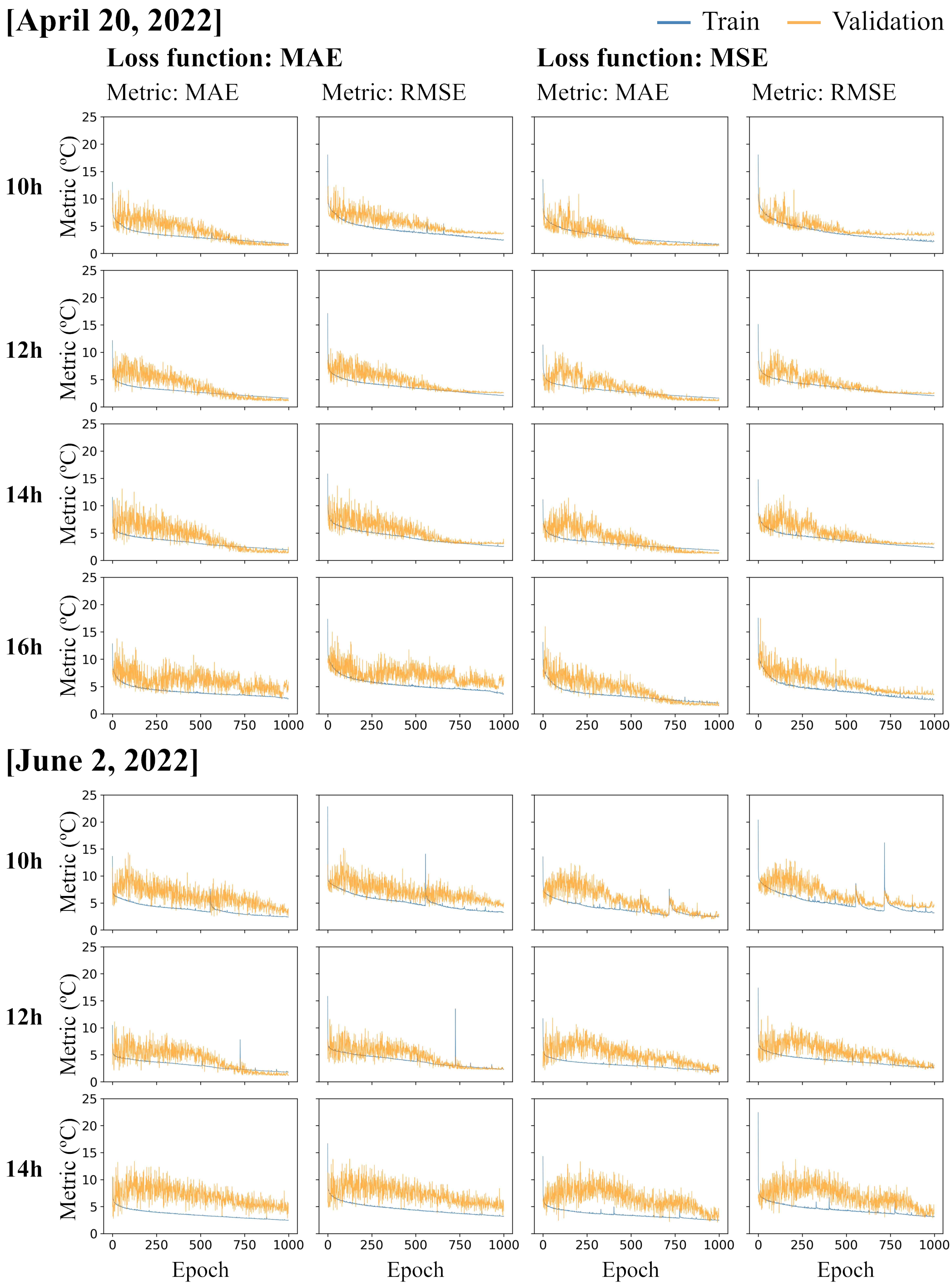

Figure 4. Performance of CNN model

The scatter plot analysis between the Tmrt predicted by the CNN model and the ENVI-met Tmrt showed that the accuracy was very high, with R2 exceeding 0.9 at all times except 14:00 on June 2. The RMSE also showed little difference, within about 3°C, except for 14:00 on June 2(Figure 5).

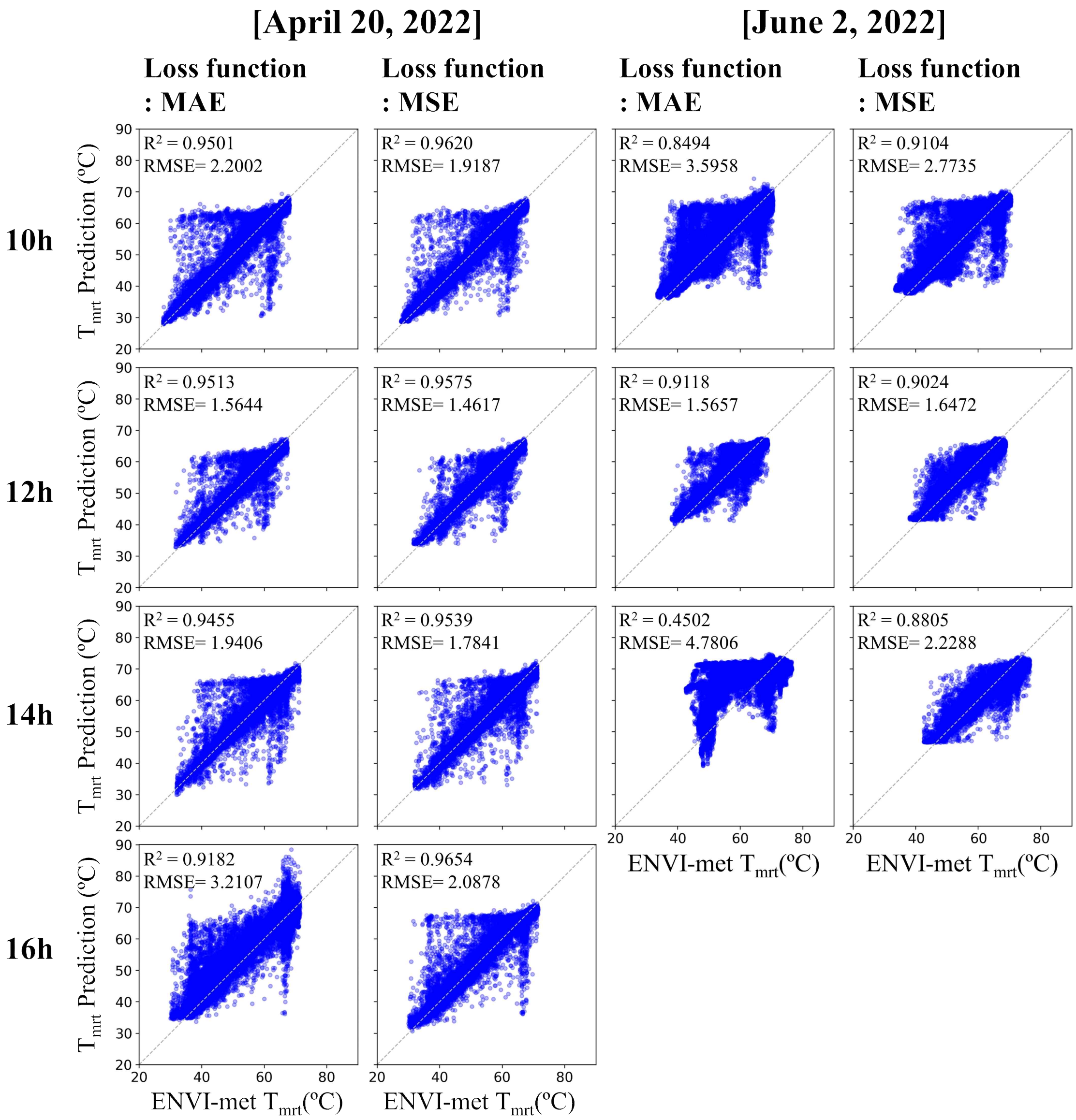

Figure 5. Scatter plot between Tmrt of ENVI-met and predicted by CNN model

Figure 6 shows the distribution of differences between ENVI-met Tmrt and Tmrt predicted by the CNN model. The difference was small, within ±2°C, in most time zones. However, at 2:00 PM on June 2, a difference of more than 10°C occurred in the tree area. This is believed to be because ENVI-met modeling did not accurately predict the tree area.

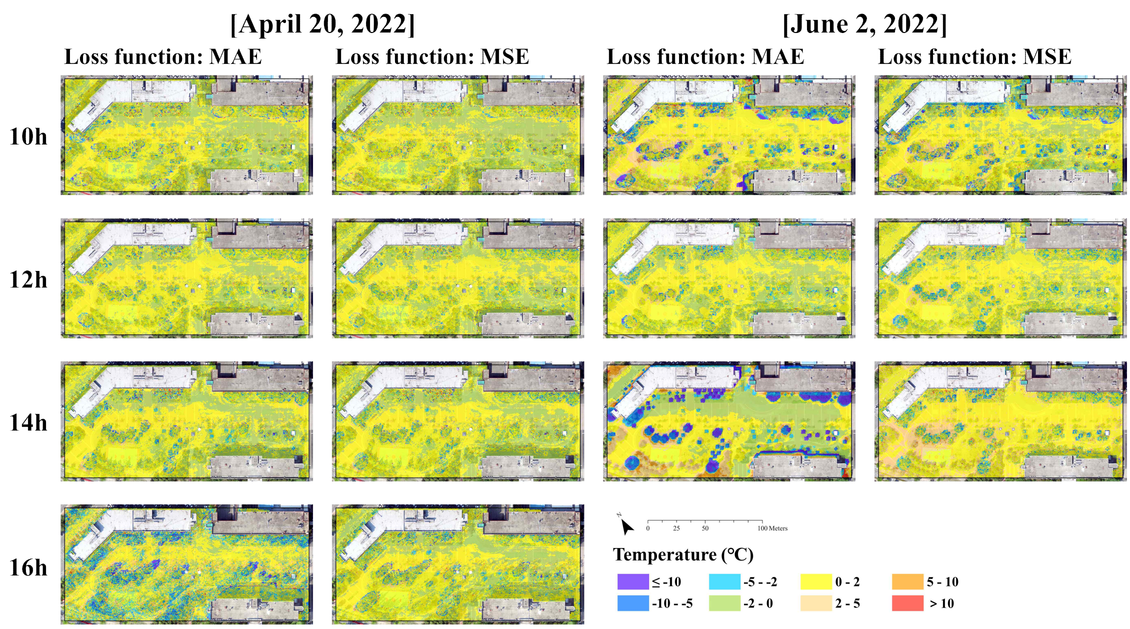

Figure 6. Distribution of difference between ENVI-met Tmrt and predicted Tmrt by CNN model

Figure 7 analyzes the distribution of the difference between the ENVI-met Tmrt and the Tmrt predicted by the CNN model. The distribution of the difference of ±2°C mostly took up 90%, but it was relatively small at less than 70% at 16:00 on April 20 and 10:00 and 14:00 on June 2. This confirms that the error of the CNN model is somewhat large. The reason for the large error is understood to be due to trees and shadows. Since UAVs cannot collect information on the area under trees, there may be some differences from the ENVI-met modeling results. In addition, it is believed that the reason for the large error is that the influence of shadows cannot be understood. It is judged that this is because it is necessary to supplement the prediction model by considering additional variables in the shadow formation area in the future.

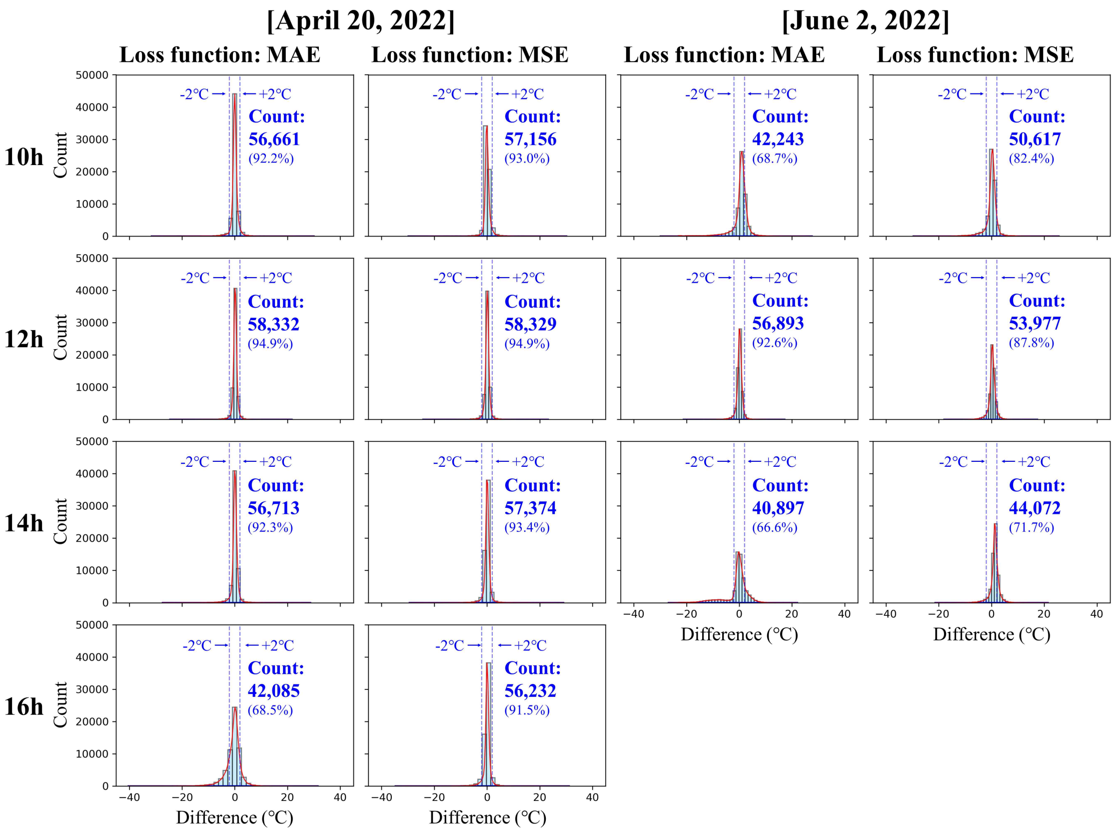

Figure 7. Histogram about difference between ENVI-met Tmrt and predicted Tmrt by CNN model

4. Conclusion

This study aimed to develop a thermal comfort prediction model using UAV and deep learning. To this end, data on the physical and thermal environments were collected from UAVs, thermal comfort simulations were performed using the ENVI-met model, and modeling was verified through field measurements. A CNN model was applied to develop a Tmrt prediction model.

As a result, the prediction accuracy was over 90% in most cases except for some times. It is believed that the times with low accuracy were due to errors caused by the influence of trees and shadows. It seems necessary to supplement the model by considering additional variables in the future.

The results of this study can be used to quickly diagnose thermal comfort in urban areas using drones. Therefore, it is believed that the results of this study can be used to quickly prepare response measures to reduce human casualties due to heat waves.