Analysis of palmar hyperhidrosis using thermal image-based heat of evaporation

Jiwon Lee  
Soonchunhyang University

Onseok Lee  (✉ leeos@sch.ac.kr)  
Soonchunhyang University

Article

Keywords: Palmar hyperhidrosis, Image processing, Evaporation heat, Thermal imagery, Machine learning, Diagnosis evaluation

Posted Date: March 23rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1463620/v1

License: ☛ ☞ This work is licensed under a Creative Commons Attribution 4.0 International License.  
Read Full License
Abstract

The condition of hyperhidrosis, which may impair one's quality of life depending on the degree of discomfort, is characterized by excessive sweating. Clinicians mainly use patient histories and questionnaires to diagnose palmar hyperhidrosis. In cases of high severity, hyperhidrosis is diagnosed through infrared thermal imaging; however, it is evaluated based on the clinician's knowledge and experience. Therefore, we intend to present an objective diagnostic method that uses a quantitative approach as an alternative to the subjective evaluation for diagnosing diseases such as hyperhidrosis. In this study, the heat of palmar evaporation was quantified and analyzed from thermal images. The higher the water in the evaporating process of residual heat from body temperature and sweat, the slower is the diffusion, and hyperhidrosis can be diagnosed depending on the degree of diffusion. The analyzed data were used as classifier training data to diagnose the state of sweating. K-nearest neighbors, one of the classifiers used, showed the best performance with 98% accuracy. This study quantitatively presents the criteria for determining the injection site for drug treatment of palmar hyperhidrosis, and can be presented as a new diagnostic evaluation method for thermal imaging-based palmar hyperhidrosis based on the phenomenon of evaporation.

Introduction

Hyperhidrosis is classified as a disease based on the amount of sweat secreted in response to emotional stimuli and the degree of discomfort experienced by the patient\textsuperscript{1}. Hyperhidrosis that occurs in specific areas such as the hand, foot, face, and armpits is called localized hyperhidrosis. Among them, palmar hyperhidrosis, which occurs on the palm, can result in social discomfort or difficulty in performing tasks as a result of sweating when shaking hands, writing, or gripping objects, which can reduce the quality of life depending on the degree\textsuperscript{2}. The clinician's knowledge and experience are essential to determining hyperhidrosis in clinical practice through questionnaires, history-taking, and visual observation. Additional digital infrared thermal imaging is also mainly subjectively evaluated\textsuperscript{3-5}. This imaging diagnostic method can check not only the sweat site but also changes in body temperature. When comparing the body temperature of both sides, a temperature difference of 0.3 °C or more reflects an abnormality, and the more distinct the difference, the greater is the likelihood of disease\textsuperscript{6-9}. In some cases, the effectiveness of the treatment was confirmed by comparing before and after results\textsuperscript{6,10-12}. In other words, when evaluating the severity of hyperhidrosis, there is insufficient objectivity. Moreover, as there are various treatment methods for hyperhidrosis, such as sympathetic surgery and drug treatment, it is necessary to objectively assess the severity of symptoms to properly customize the treatment plan\textsuperscript{10,13-15}.

Drug medication therapy for palmar hyperhidrosis involves injecting drugs, such as botulinum toxin, into several dozen localized areas on the fingers and palms. Because there are many sweat glands on each finger and palm, a total of 15–36 topical areas are subcutaneously injected\textsuperscript{5,16}. An iodine-starch test can be conducted to determine sweat release and treatment sites; however, this is a time-consuming and
inconvenient method for patients, and therefore, under-considered\(^2\),\(^17\). In addition, because the points where iodine mixed with sweat and starch react may not always become injection sites, a 1 cm grid is drawn to determine the injection site. Evidently, the criteria for determining the treatment site for drug injections for palmar hyperhidrosis are not clearly defined.

When water is included in the process of increasing or decreasing the temperature of an object, evaporation occurs and hydraulic continuity may be compromised until thermal equilibrium is achieved\(^1\),\(^18\). In other words, the slow diffusion that occurs during evaporation is characterized by an unstable temperature change. Therefore, depending on the amount of water and evaporation, the more the sweating caused by palmar hyperhidrosis, the more is the distinctive diffusion. Accordingly, the slower the diffusion, the more likely it is that sweat exists at the point of occurrence. Therefore, thermal imaging frames of palmar hyperhidrosis are divided into local regions to analyze their characteristics. Thus, we propose a method for quantitatively determining the treatment site for drug injection simultaneously with diagnosis. In addition, because evaporation and diffusion can occur even at the boundary of separated local areas, the same analysis method was applied to the entire area for comparison. Finally, this study proposes an objective diagnostic evaluation method for palmar hyperhidrosis by investigating the heat of evaporation of water using thermal imaging-based methods.

**Results**

**Analysis results from thermal sequence images of the palmar area**

As the heat from the skin was transferred and the residual heat on the plate evaporated, the pixel value gradually decreased in the thermal image. When sweating is caused by hyperhidrosis, the skin temperature of the affected area is lowered owing to the evaporation of sweat, and the lower the body temperature, the more rapidly the image changes. Figure 1 compares hand data on both sides (right: Rt, left: Lt) for the abnormal group (Ab) and the normal group (Nor). Analysis using the entire hand area is called whole analysis (WA), and analysis using the local area is called local analysis (LA). Even on the palm, the area and amount of sweating may differ from person to person. Therefore, two methods, carried out on the same person, were analyzed and compared to perform a quantitative evaluation by confirming the location. The LA was analyzed locally by dividing the hand into eight areas, which were the five fingers and three sections of the palm. The results showed data from a central region, including a concave portion of the palm (P), which is the section of the palm that sweats the most, and a second finger (F) region, which is the finger used the most (Figure 1). The x-axis in Figure 1A represents the index of the thermal image frame. The y-axis shows the change in intensity for each frame, which is the value obtained by subtracting the average intensity value of the first frame from the corresponding frame. The WA showed a substantial change in intensity, whereas LA showed a minor change.

Most importantly, in Nor, a range stands out in comparison to Ab. In Figure 1, the blue and the red areas represent Nor and Ab, respectively. The LA in Figure 1B was set identically to the WA in Figure 1A. For thermal imaging, the hands were placed on the plate for 10 s, and then removed. In other words, the
imaging starts when the temperature of the hand is sufficiently transferred and immediately after the hand is removed. And, as seen in the figure, from the first frame of the image to before the frame of the box area, the temperature of the hand transferred to the plate evaporates quickly. That is, because the heat transferred to the plate is high, it has a high-intensity value in the grayscale image. As there is no longer a continuous heat transfer, thermal evaporation occurs, and the temperature rapidly decreases and the intensity decreases. The lower the ambient temperature, the greater is the reduction. At the same time, the more sweat there is, the more likely it is that there is water on the plate. This also contributes to the rapid change in evaporation. The evaporation process occurs continuously in which the surface temperature of the water decreases slowly until thermal equilibrium with the surrounding environment is achieved. Subsequently, from the frame corresponding to the box areas, it can be observed that the intensity increases as diffusion occurs and then decreases again. This demonstrates a collapsing linearity, which gradually decreases in value because the continuity between the water and vaporization planes is impaired by diffusion as the water content decreases. The more water there is, the higher is the surface temperature and the slower is the evaporation rate owing to slow diffusion. In the case of Nor with little sweat, a large diffusion was confirmed in the blue box area, and in the case of Ab with excessive sweat, diffusion was confirmed in the red box area (Figure 1A). And Ab was identified in later frames than Nor. The same phenomenon can be observed in all graphs of Rt. When the hand is humid or wet, and sweat is present, evaporation is thought to be limited by slow diffusion. Therefore, in the case of Ab, diffusion can be confirmed from a subsequent thermal image frame. In particular, in the data of Lt in Figure 1A, it can be seen that there were several diffusion sections (blue box areas), which were prominently displayed in Nor and gradually appeared longer. On the other hand, in the case of Ab data of Lt, it can be said that maintaining a constant intensity change from any frame achieves thermal equilibrium with the surrounding temperature. Because it was difficult to confirm the pronounced diffusion phenomenon, the intensity was directly approached and confirmed for each frame, and as a result, it was close to zero. This means that there is little change in the intensity because the transferred heat moves rapidly and the temperature becomes equal to the surrounding temperature.

Figure 1B confirms the intensity difference between the thermal image frames, and the y-axis represents the value obtained by subtracting the average intensity value of the corresponding frame from the previous frame. As the residual heat and sweat evaporate, the amplitude decreases. However, owing to slow diffusion, it is possible to see a section in which the amplitude of the previous frame changes significantly. Similarly, as in the box areas shown, in Nor, the value fluctuates considerably for a particular frame owing to diffusion. In the case of Ab with sweat, the more water it has, the slower the diffusion appears, and it can be seen that the data has a relatively low amplitude. Both groups showed rapid changes in the initial stage; however, in particular, the Ab group had a relatively low body temperature because of sweating. Therefore, the initial range of change is considered to be relatively large. Data analysis of various cases is necessary to generalize this phenomenon.

LA, the result of the local analysis, includes results for P, which is the mid-palm area, and F, which is part of the second finger. This can also be interpreted in the same manner as described above. During evaporation, diffusion was confirmed in the frame corresponding to the box areas, and in the case of Ab,
diffusion was confirmed in a later frame. A thermal equilibrium state with almost no change in intensity was also confirmed. Interestingly, in the result of the F region for LA (Rt) in Figure 1, the Ab data appeared to have achieved almost thermal equilibrium because the intensity was almost zero within the thermal image frame; however, it was confirmed that it had a non-zero intensity value from the 42nd frame onwards. Thermal energy overlaps at certain boundary points while slowly evaporating and diffusing slightly from the central area where most heat is conducted to the edge of the finger. In addition, it can be seen that the drastic change due to evaporation at the beginning is relatively smaller in the F data than that in the P data. Because the finger is a peripheral body part, it cools faster than the palm, and this data confirms that it has a lower body temperature than it.

Figure S2 shows the data of the other subject for the results shown in Figure 1. Initially, it shows a drastic change due to evaporation, followed by a diffusion section from the frame corresponding to the box areas. In graph A, the average intensity change increases and then decreases; in graph B, for the same section, the amplitude increases more sharply than that in the previous frame. It was confirmed that Ab appeared at a lower rate than Nor.

Hyperhidrosis is often accompanied by cold hands and feet because the temperature of local areas, such as the hands, becomes cold as a result of sweating. Rheumatoid arthritis (RA) may be the underlying cause of cold hands and feet. When diagnosing the thermography of RA, the temperature difference between the fingertips (second, third, and fourth) and the palm area is obtained and compared for both sides. In the case of the palm, the central region is checked; however, owing to the characteristics of our experiment, analysis is performed from the transferred heat based on the thermal image. Therefore, the average intensity of the four palm regions and the intensity difference between the three fingertips were obtained. The corresponding areas when handling the WA data are shown in Figure S1A. Figure 2 shows the temperature difference between the fingers and palms on both sides. In the case of Nor, the temperature difference was not large. Owing to evaporation, the temperature difference decreased. On the other hand, Ab had a large temperature difference between the fingers and palms; therefore, a rapid temperature decrease was observed in the beginning, indicating that the temperature of the hand was low at the time of imaging.

The results obtained from the subjects of the Figure S2 data can be seen in Figure S3. Nor did not show a significant difference because the temperature difference between the fingers and the palm was similar; however, in the case of the fourth finger on both sides, a large temperature difference was initially observed. Ab also showed a large initial change, indicating that the temperature of the finger was lower than that of the palm, more than Nor.

Figure 3 shows the intensity changes extracted from the second finger and mid-palm regions, which are representatively used when evaluating hyperhidrosis using the LA method. LA uses each mask image for a palm region separated into five fingers and three palm sections. Three intensity values were extracted from each mask image to confirm these changes (Figure S1B). Figure 3 also confirms the intensity change, which decreases owing to evaporation in both regions. The intensities of the three spots show
evaporation at different values and different rates. Furthermore, it can be seen that the Ab spots show a sharp change at the beginning compared with those of Nor. The blue and red box areas indicate the same frame as in Figure 1, where prominent diffusion phenomena in Nor and Ab are shown. If the value does not change after a certain time, the image intensity is zero, which is considered to be in thermal equilibrium with the ambient temperature. However, in Ab of Figure 3A, the intensity of three spots gradually increased from the 41st–43rd thermal image frames, which are considered to be affected by the diffusion of the surrounding area.

Similarly, the results for the other study subject are shown in Figure S4. The blue and red box areas in this figure indicate the same frame as in Figure S2, where prominent diffusion phenomena in Nor and Ab are shown. In each dataset, it can be seen that the intensity changes because of evaporation, and diffusion occurs at a slow rate. In the case of Ab, a sudden change in the initial stage can be observed owing to water. In particular, the constant section, which can be confirmed in Ab of B, is in a state in which the surface temperature is in thermal equilibrium with the ambient temperature. In fact, the intensity is zero from the 5th, 7th, and 11th thermal image frames for each spot.

**Analysis of the questionnaire results of subjects**

Two types of questionnaires were filled out during the experiment. One was the existing questionnaire used to diagnose hyperhidrosis (hyperhidrosis evaluation questionnaire, HDSS), and the other was a questionnaire (palmar hyperhidrosis condition questionnaire, PHCQ) developed by combining the existing hyperhidrosis questionnaire items with items most associated with hyperhidrosis symptoms. Each set consisted of nine and six items, respectively. The purpose of the PHCQ was to examine the condition of the subjects’ hands and ascertain whether sweat, which was the experimental condition of this study, was well-formed. It was further determined that the results of this experiment would be considered reliable if a clear state change was observed. Therefore, corrected item-total correlation coefficients (CITC) were calculated to evaluate whether each questionnaire had internal consistency, that is, for which conditions it was asked consistently.

The CITC results for HDSS are shown in Table 1. There are a total of nine items (H1 to H9); however, H5, H6, and H9 have zero variation, that is, all subjects surveyed had the same score. Therefore, the calculation was omitted and calculated as the result of type A. Usually, a correlation value of 0.7–0.8 (item-adjusted total correlation) indicates an acceptable Cronbach’s alpha, and a value lower than this is an unreliable scale. Therefore, re-evaluation was performed by removing items with low correlation to identify and evaluate the internally matching questionnaire items. Type B was the result of re-evaluation by removing H2 and H8, which showed the lowest correlation in Type A, with 0.0232 and 0.0719, respectively. The total Cronbach’s alpha for Type A also increased from 0.6303 to 0.7692. Type B was also re-evaluated by removing H7, which showed the lowest correlation with 0.3314, and the result was Type C. Finally, the total Cronbach’s alpha value improved to 0.8936, and it was confirmed that the subjects of this study had particularly good internal consistency for H1, H3, and H4 items.
The CITC results for the PHCQ are shown in Table 2. There are a total of six questionnaire items. The left and right hands were investigated (DL1–6, DR1–6, WL1–6, and WR1–6) for the usual hand condition (dry, D) and the altered hand condition (wet, W). This questionnaire was designed with reference to the existing questionnaire for diagnosing hyperhidrosis to verify whether the experimental factors considered in this study were well-formed and the results analyzed from such data were reliable. In both the D and W cases, 0.8210 and 0.8540 were found to have good internal consistency. Therefore, it can be confirmed that all items are worthy of retention, which means that the results of this study, conducted for an objective evaluation of hyperhidrosis, can be trusted.

Classification of hyperhidrosis

In this study, the presence or absence of sweat, which is a symptom of hyperhidrosis, was binary classified, and the experiment was conducted assuming that Nor was the normal group and Ab was the abnormal group. Among the six machine learning classifiers used for classification (ECOC-SVM, decision tree, discriminant analysis, K-nearest neighbors, random forest, and AdaBoost), the result of K-nearest neighbors showed the best performance with an accuracy of approximately 98%, and the random forest results showed the second-best performance with an accuracy of approximately 91% (Table 3). The Matthews correlation coefficient (MCC) suggests that the closer it is to 1, the better is the prediction of both classes, even if the data are unbalanced. For all metrics, the K-nearest neighbors showed the best results. K-nearest neighbors are considered to have shown excellent results because classification is performed using only the data. In the case of random forest, which showed suboptimal performance, a bagging method that generates multiple data samples through random sampling and trains them differently showed sufficiently easy and intuitive prediction performance. However, further improvement of performance by strengthening randomness was limited because similar or a small number of model types were trained. In the case of other models, such as ECOC-SVM, decision tree, discriminant analysis, and AdaBoost, performance can be improved if more diverse feature data are trained. Figure 4 shows the receiver operating characteristic (ROC) curve for performing cross-validation on the trained classifier to evaluate the classifier performance equally. The area under the curve (AUC) for all classifiers were above 0.8, indicating good classification performance.

Hyperhidrosis evaluation system

In this study, an application system and protocol capable of objective analysis were established for the accurate diagnosis of palmar hyperhidrosis (Figure S5). When basic personal information of a patient, such as name, date of birth, and gender, is input into this system, a coded folder is automatically created, and accessibility is improved by including a function to automatically collect thermal images through the corresponding path. In addition, it is possible to check the graph results analyzed from the collected thermal images and the history of accumulated patient data simultaneously; thus, a comparative analysis is possible, and the prediction result of the presence or absence of hyperhidrosis can be confirmed.
Discussions

In this study, a diagnostic solution algorithm that can analyze the heat of evaporation of the hand using an IR camera was studied, and a machine learning binary classification was performed to determine whether the features of the sweat calculated by the developed algorithm could be well distinguished. When a patient with hyperhidrosis experiences sweating due to sympathetic nerve stimulation, the skin temperature of the affected area decreases because of the evaporation of sweat. This was analyzed using an IR camera, and it was confirmed that the pixel value sharply decreased as the body temperature decreased. Thus, the whole and local areas of the hand were comparatively analyzed. The principle has not previously been used to diagnose hyperhidrosis, and because it presents quantitative results, it can be proposed as an objective diagnostic system.

As with the size of each individual's hand, the body temperature varies as well. In patients with hyperhidrosis, when sweating occurs on the hands, the body temperature of the sweating area is lower than that of other normal areas because of the heat of evaporation of water. Because the decrease in temperature is also different for each patient, the results cannot be objectively compared and analyzed. For this purpose, a diagnostic evaluation of hyperhidrosis was conducted using the basic principle that body heat is transmitted and pixel values are clearly displayed when confirmed by thermal imaging. In particular, when water, such as sweat, was present, the evaporation heat was analyzed, and the features of this data were identified while capturing diffusion. In addition, as the water content increased, diffusion occurred at a slower rate, which limited evaporation. Accordingly, as shown in Figure 1, diffusion occurred at all points where the value decreased and then increased. In fact, when the frame image was checked together, there were cases where the intensity of the hand object was partially strengthened and cases where the image brightness increased overall, including the intensity of the background. The IR camera device included a self-calibration function. To solve this problem, we tried to devise a correction equation that is adaptively taken for the degree of change; however, it was not applied because performing the correction could disrupt the pure features of the data, which are highly sensitive.

In addition, this study attempted to quantitatively evaluate palmar hyperhidrosis more locally by comparatively analyzing both WA and LA methods. As shown in Figures 1A and S2, when analyzed with WA, the temperature change continued, whereas in LA, as shown in Figures 3A, D, and S2B, in some sections, it was confirmed that thermal equilibrium with the ambient temperature was achieved. It was possible to determine in which part the temperature change ended or continued, quantifying and describing the temperature change for the hands. In particular, the more water present, the slower the diffusion appears, which can objectively help determine which part sweats more locally.

This study aims to develop a system that can objectively evaluate the diagnosis of palmar hyperhidrosis. Therefore, a review of clinical applicability was considered; however, establishing an easy-to-implement system from data collection to intuitive result confirmation in a clinical environment was prioritized. Thus, we intend to perform various case analyses and system expansion or optimization targeting actual patients with hyperhidrosis. Therefore, this study developed a diagnostic evaluation system and protocol
for palmar hyperhidrosis, and the experiment was conducted with ten healthy subjects. Tables S1 and S2 summarize the survey results to understand the basic information and data results of the study subjects.

In this study, Type C, which eliminated a few items, had the largest increase in the alpha value. An examination of the eliminated items revealed the discomfort of changing socks or stockings, walking barefoot, and developing eczema on the hands and feet. Considering that this study was a pilot study for developing a hyperhidrosis diagnostic system, it was conducted on healthy individuals rather than on people experiencing discomfort due to palmar hyperhidrosis. In other words, the items, which had no relevance for people of all subjects (n = 10), were removed. On the other hand, the remaining items reflected the inconvenience of shaking hands, holding objects, and turning objects, such as bottle caps. These three cases represent typical discomfort that can be felt even when a small amount of sweat occurs, and it was found that some study subjects suffered these symptoms regularly.

As a result, the binary classification result was excellent for sweat, and if we secure data from actual hyperhidrosis patients and analyze the patterns for various cases, it will be possible to classify the severity of hyperhidrosis more accurately.

Conclusions

In this study, the evaporation heat of the hand was analyzed using a thermal image obtained with an IR camera, and the feature difference according to sweat was confirmed.

When administering drug treatment for palmar hyperhidrosis, it is injected into several areas because the palm has many sweat glands. In other words, thermal imaging-based evaluation of hyperhidrosis may cause local evaluation factors to be missed when performing global analysis of the hand or palm. Therefore, a new approach is required. This study compared the results of the global and more local analyses of the hand, and it was possible to quantitatively evaluate the difference in the change in evaporation and diffusion based on the amount of sweat. In addition, the reliability of the data was increased through additional questionnaires, and it was confirmed that the features of sweat were distinguished through the excellent performance results of the machine learning classifiers. This study is the first new diagnostic solution for the quantitative evaluation of palmar hyperhidrosis by objectifying basal body temperature and hand size according to individual constitution. In the future, we plan to secure hyperhidrosis disease data, classify the severity, and conduct generalization studies.

Methods

Data acquisition

In our experiment, a FLIR C2 thermal imaging camera (FLIR system, Inc., Wilsonville, OR, USA) was used, and thermal imaging was performed in a dark room environment controlled by external environmental factors based on medical thermal imaging-related papers (indoor temperature 20 ± 0.5°C, humidity 35 ± 5%)\(^7,9,19\). This system was equipped with two new pieces of equipment. One is a plate in contact with the
diagnostic part of the hand, and the other is a body thermal diagnosis device that can capture the contact area while fixing a thermal infrared camera (IR camera). They were constructed of a black, 5 mm thick acrylic material that is less susceptible to external influences. If the thermal conductivity is too high or too low, such as in glass or wood, the temperature change is more significant, making it difficult to capture a thermal image in a meaningful section.

The characteristic of our experiment was not to capture a body object with a thermal imaging camera but to capture the separated area after the palm was in close contact with the plate for 10 s. Hyperhidrosis was evaluated by analyzing the heat of water evaporation from the transferred heat of the hand. Images of the back of the hand were collected during close contact, which were then used to create a split mask for the hand region, and 61 thermal image frames were collected by capturing at 3 s intervals for 3 min (Figure 5). The temperature range was fixed at 20–40 °C to include body temperature in various states.

This is a pilot study for the diagnosis of hyperhidrosis through the detection of the heat of evaporation due to sweat. There were two experimental groups. The normal group (Nor) was subjected to the experiment under no constraint, similar to the usual condition, as the control data. The abnormal group (Ab) asked the study subjects to proceed with the experiment after wearing latex gloves for 1 h and 30 min for data analysis in case of sweating.

In this study, to conduct research using image data collected directly from the clinic, the participating institutions, Soonchunhyang University, were approved according to the guidelines of the Institutional Review Board of each institution, and the research was conducted in accordance with the ethical principles of the Declaration of Helsinki (Approval number: 1040875-202109-SB-081). Ten members of the general public without specific exclusion criteria such as gender, age, and health status (Table S1), who provided informed consent before participating, were recruited as study subjects.

Data processing for analysis

This experimental image was taken in gray mode to facilitate image processing and then converted to 8-bit grayscale before use. The images of the hand were cropped to 200 × 200 pixels. Gaussian filtering (sigma = 2) for removing noise that spreads from the back of the hand image and flat field correction (sigma = 30) for approximation of shadow components were performed to detect temperature marks in thermal images. Then, the Canny operation contours were extracted. To remove the background object, the contours were maintained by performing dilation and erosion operations before and after. Finally, a hand mask image was generated by filling the inside of the object using the imfill function. The mask image of the intact hand object was used when analyzing the whole hand (WA). In addition, because the degree of sweating in each specific area may be different for palms with countless sweat glands, the hand was divided into areas (LA). A mask image was generated from binary images of each area separated into five fingers (thumb, index finger, middle finger, ring finger, and small finger) and three palm sections (Figure 5B).
To evaluate hyperhidrosis, the heat of evaporation in the hand area was analyzed, and as a result, a clear pattern based on the amount of sweat was distinguished. In the hand mask image of WA, a total of seven spots were taken at three points on the fingertips of the thumb, index, and middle fingers along with four points on the palm, and the intensity values of the corresponding point coordinates were obtained from the thermal image frame (spotWA). The 2nd–4th fingertips are candidate regions used for temperature confirmation in rheumatoid arthritis diagnoses based on thermography\(^9\). In this study, the temperature change was confirmed as the difference between the average of the intensity values corresponding to the palm and the values corresponding to each finger (spotDiff). By extracting the intensity of three locations from each hand mask image of LA, we attempted to check the temperature distribution for each local area of the hand (spotLA). The location where the pixels were extracted can be confirmed using the supplementary data (Figure S1). In both cases, each generated mask image was added to each thermal image frame to obtain the sum and average of the intensity values. Then, to check the average intensity value change of the frame image, the data obtained by subtracting the value of the first frame for each frame examined (Avg). For each frame, the average intensity value of the previous frame was subtracted to confirm the data change of successive thermal images (AvgDiff). These analysis parameters were used as training data for the machine learning classifiers in Nor and Ab classification. The number of parameters used was 1080 from WA and LA for eight areas per person (Table S2).

**Survey and statistical analysis**

To examine the results of this system developed for the diagnosis and evaluation of hyperhidrosis, subjects were asked to answer six items of the main diagnostic criteria (MDC) questionnaire and nine items of the hyperhidrosis evaluation questionnaire (HDSS)\(^2,5,20,21\). The MDC items can be seen in Table S3. If symptoms last more than six months and excessive sweating occurs in a specific area, meaning two or more of these items apply, it is an indicator of hyperhidrosis.

The existence of the experimental factors for creating sweat and the reliability of the results were confirmed through the palmar hyperhidrosis condition questionnaire (PHCQ) completed immediately after both experiments (Nor and Ab groups) (Table S4). The PHCQ was developed by our research, in addition to the hyperhidrosis scale, health-related quality of life of hyperhidrosis, dermatology life quality index, and hyperhidrosis evaluation questionnaire, which are used in clinical research for hyperhidrosis\(^2,10,20,21\). The list consisted of items considering the most frequently complained-about conditions. This questionnaire consisted of six items pertaining to sweat, coldness, dryness, emotional stress, status change, and difficulty in using tools (Table S5).

The degree of internal consistency between the questionnaire items was evaluated using CITC, which is a reliability evaluation scale. Cronbach's alpha obtained from this evaluation indicates that the closer the value is to 1, the stronger is the internal consistency. If a respondent tends to pick a high score on one item, it means that they are more likely to pick a high score on the other item.

**Machine learning classifier and metrics**
To present a diagnostic evaluation solution for hyperhidrosis based on the amount of water loss, we analyzed the sweat features by capturing the evaporation and diffusion phenomena for locally accumulated sweat and residual heat using these parameters. The classification performance was evaluated by performing a ten-fold cross-validation on the trained classifier. The accuracy, specificity, sensitivity, precision, and F1-score were used as the evaluation metrics of the machine learning classifier. Accuracy is the most intuitive metric for checking the model performance. Specificity is the ratio of those that are actually false to those judged to be false. Sensitivity and precision are the ratios of what the model actually predicted to be true to the data classified as true; however, the two metrics have different perspectives on whether the model relied on predictions or the actual data, respectively. Therefore, they were considered and used complementary to each other, and the higher the value, the better is the model. For the reliability of these two metrics, the F1-score was checked to evaluate the performance by combining it with a relatively high value when the precision and sensitivity were not biased either way. The MCC, which calculates the correlation coefficient assuming two classes as two variables, was used as a binary classification evaluation metric. The better the prediction, the closer the value is to one. Finally, the ROC curve and AUC were obtained to confirm model performance. All data processing was performed using Matlab2021a (MathWorks, Inc., Natick, MA, USA).

Declarations

Acknowledgments

This study was supported by the Soonchunhyang University Research Fund, the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2022R1A2C1010170) and the Ministry of Education (No. 2020R1A6A3A13075858).

Competing interests

The authors declare no competing interest.

Author contributions

O.L. conceived of the study with J.L. and performed the review of all parts; J.L. performed dataset acquisition, algorithm design and analysis, and writing; All authors contributed to the text manuscript and reviewed the final submission.

References


Tables

**Table 1. Corrected item-total correlation coefficients (CITC) result of the hyperhidrosis evaluation questionnaire (HDSS) conducted to verify the diagnosis evaluation results of hyperhidrosis.** The scale was used to evaluate the reliability of the internal consistency of the questionnaire, and it was based on the results of the questionnaire survey of ten subjects who were recruited for this study. The questionnaire consisted of a total of nine questions (H1~H9). For type A, the initial calculation result, the variable with zero variation was omitted, and then the reevaluation results (type B and C) are shown by eliminating items with low correlation. Finally, it was confirmed that Cronbach's Alpha improved to 0.8936 and had good internal consistency (SD; standard deviation, Adj.; adjusted, Corr.; correlation).
<table>
<thead>
<tr>
<th>Type</th>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Adj. Total Mean ± SD</th>
<th>Item-Adj. Total Corr.</th>
<th>Squared Multiple Corr.</th>
<th>Cronbach's Alpha Total</th>
<th>Cronbach's Alpha Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>H1</td>
<td>1.0909 ± 0.3015</td>
<td>5.909 ± 1.136</td>
<td>0.6104</td>
<td>1.0000</td>
<td>0.5106</td>
<td>0.6303</td>
</tr>
<tr>
<td></td>
<td>H2</td>
<td>1.0909 ± 0.3015</td>
<td>5.909 ± 1.300</td>
<td>0.0232</td>
<td>1.0000</td>
<td>0.6855</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H3</td>
<td>1.1818 ± 0.4045</td>
<td>5.818 ± 1.079</td>
<td>0.5417</td>
<td>1.0000</td>
<td>0.5078</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H4</td>
<td>1.0909 ± 0.3015</td>
<td>5.909 ± 1.136</td>
<td>0.6104</td>
<td>1.0000</td>
<td>0.5106</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H7</td>
<td>1.3636 ± 0.5045</td>
<td>5.636 ± 1.027</td>
<td>0.4738</td>
<td>0.6633</td>
<td>0.5388</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H8</td>
<td>1.1818 ± 0.4045</td>
<td>5.818 ± 1.250</td>
<td>0.0719</td>
<td>0.5926</td>
<td>0.6977</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>H1</td>
<td>1.0909 ± 0.3015</td>
<td>3.6364 ± 0.9244</td>
<td>0.8480</td>
<td>1.0000</td>
<td>0.6064</td>
<td>0.7692</td>
</tr>
<tr>
<td></td>
<td>H3</td>
<td>1.1818 ± 0.4045</td>
<td>3.5455 ± 0.9342</td>
<td>0.5052</td>
<td>0.4762</td>
<td>0.7500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H4</td>
<td>1.0909 ± 0.3015</td>
<td>3.6364 ± 0.9244</td>
<td>0.8480</td>
<td>1.0000</td>
<td>0.6064</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H7</td>
<td>1.3636 ± 0.5045</td>
<td>3.3636 ± 0.9244</td>
<td>0.3314</td>
<td>0.2143</td>
<td>0.8936</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>H1</td>
<td>1.0909 ± 0.3015</td>
<td>2.2727 ± 0.6467</td>
<td>0.8859</td>
<td>1.0000</td>
<td>0.7826</td>
<td>0.8936</td>
</tr>
<tr>
<td></td>
<td>H3</td>
<td>1.1818 ± 0.4045</td>
<td>2.1818 ± 0.6030</td>
<td>0.6708</td>
<td>0.4500</td>
<td>1.0000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H4</td>
<td>1.0909 ± 0.3015</td>
<td>2.2727 ± 0.6467</td>
<td>0.8859</td>
<td>1.0000</td>
<td>0.7826</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Corrected item-total correlation coefficients (CITC) result of the new palmar hyperhidrosis condition questionnaire (PHCQ) conducted to verify the diagnosis evaluation results of hyperhidrosis. This questionnaire was designed with reference to the existing questionnaire for diagnosing hyperhidrosis to verify whether the experimental factors for sweating of the hand intended in this study were well-formed and whether the results analyzed from such data are reliable. It consists of six questionnaires on the condition of both hands, and the subjects' feelings about the usual hand
condition (D) and the altered hand condition (W) were recorded numerically. In both experiments, Cronbach's Alpha was 0.8 or higher, indicating good internal consistency (L; left, R; right).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Adj. Total Mean ± SD</th>
<th>Item-Adj. Total Mean ± SD</th>
<th>Cronbach's Alpha</th>
<th>Total Cronbach's Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL1</td>
<td>1.545 ± 0.688</td>
<td>21.545 ± 6.170</td>
<td>0.3943</td>
<td>0.8142</td>
<td><strong>0.8210</strong></td>
</tr>
<tr>
<td>DL2</td>
<td>2.091 ± 0.831</td>
<td>21.000 ± 6.261</td>
<td>0.1922</td>
<td>0.8286</td>
<td></td>
</tr>
<tr>
<td>DL3</td>
<td>2.273 ± 1.104</td>
<td>20.818 ± 5.980</td>
<td>0.3719</td>
<td>0.8187</td>
<td></td>
</tr>
<tr>
<td>DL4</td>
<td>2.273 ± 1.191</td>
<td>20.818 ± 5.546</td>
<td>0.7350</td>
<td>0.7801</td>
<td></td>
</tr>
<tr>
<td>DL5</td>
<td>2.000 ± 0.894</td>
<td>21.091 ± 5.787</td>
<td>0.7341</td>
<td>0.7859</td>
<td></td>
</tr>
<tr>
<td>DL6</td>
<td>1.273 ± 0.467</td>
<td>21.818 ± 6.096</td>
<td>0.7918</td>
<td>0.7997</td>
<td></td>
</tr>
<tr>
<td>DR1</td>
<td>1.727 ± 1.009</td>
<td>21.364 ± 6.249</td>
<td>0.1442</td>
<td>0.8368</td>
<td></td>
</tr>
<tr>
<td>DR2</td>
<td>2.091 ± 0.831</td>
<td>21.000 ± 6.261</td>
<td>0.1922</td>
<td>0.8286</td>
<td></td>
</tr>
<tr>
<td>DR3</td>
<td>2.182 ± 1.079</td>
<td>20.909 ± 5.924</td>
<td>0.4410</td>
<td>0.8116</td>
<td></td>
</tr>
<tr>
<td>DR4</td>
<td>2.273 ± 1.191</td>
<td>20.818 ± 5.546</td>
<td>0.7350</td>
<td>0.7801</td>
<td></td>
</tr>
<tr>
<td>DR5</td>
<td>2.000 ± 1.000</td>
<td>21.091 ± 5.770</td>
<td>0.6586</td>
<td>0.7906</td>
<td></td>
</tr>
<tr>
<td>DR6</td>
<td>1.364 ± 0.505</td>
<td>21.727 ± 6.117</td>
<td>0.6834</td>
<td>0.8028</td>
<td></td>
</tr>
<tr>
<td>WL1</td>
<td>3.364 ± 1.027</td>
<td>28.545 ± 6.962</td>
<td>0.8926</td>
<td>0.8170</td>
<td><strong>0.8540</strong></td>
</tr>
<tr>
<td>WL2</td>
<td>2.727 ± 1.104</td>
<td>29.182 ± 7.054</td>
<td>0.7262</td>
<td>0.8279</td>
<td></td>
</tr>
<tr>
<td>WL3</td>
<td>3.182 ± 1.079</td>
<td>28.727 ± 7.444</td>
<td>0.3555</td>
<td>0.8546</td>
<td></td>
</tr>
<tr>
<td>WL4</td>
<td>1.818 ± 1.079</td>
<td>30.091 ± 7.463</td>
<td>0.3377</td>
<td>0.8558</td>
<td></td>
</tr>
<tr>
<td>WL5</td>
<td>3.273 ± 1.104</td>
<td>28.636 ± 7.032</td>
<td>0.7484</td>
<td>0.8262</td>
<td></td>
</tr>
<tr>
<td>WL6</td>
<td>2.000 ± 1.095</td>
<td>29.909 ± 7.687</td>
<td>0.1188</td>
<td>0.8705</td>
<td></td>
</tr>
<tr>
<td>WR1</td>
<td>3.273 ± 1.009</td>
<td>28.636 ± 6.990</td>
<td>0.8804</td>
<td>0.8183</td>
<td></td>
</tr>
<tr>
<td>WR2</td>
<td>2.455 ± 1.128</td>
<td>29.455 ± 7.147</td>
<td>0.6168</td>
<td>0.8361</td>
<td></td>
</tr>
<tr>
<td>WR3</td>
<td>3.000 ± 1.000</td>
<td>28.909 ± 7.382</td>
<td>0.4606</td>
<td>0.8471</td>
<td></td>
</tr>
<tr>
<td>WR4</td>
<td>1.636 ± 0.924</td>
<td>3.273 ± 7.485</td>
<td>0.3916</td>
<td>0.8512</td>
<td></td>
</tr>
<tr>
<td>WR5</td>
<td>3.182 ± 1.079</td>
<td>28.727 ± 7.115</td>
<td>0.6847</td>
<td>0.8313</td>
<td></td>
</tr>
<tr>
<td>WR6</td>
<td>2.000 ± 1.095</td>
<td>29.909 ± 7.582</td>
<td>0.2167</td>
<td>0.8641</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Results of binary classification on the sweat in the thermal image-based palmar data. Among the five classifiers used, K-nearest neighbors showed the best accuracy of 98%, followed by random forest with an accuracy of approximately 91%.

<table>
<thead>
<tr>
<th></th>
<th>ECOC-SVM</th>
<th>Decision Tree</th>
<th>Discriminant analysis</th>
<th>K-nearest neighbors</th>
<th>Random Forest</th>
<th>Adaboosting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accuracy</strong></td>
<td>0.8894</td>
<td>0.8231</td>
<td>0.8764</td>
<td><strong>0.9774</strong></td>
<td><strong>0.9082</strong></td>
<td>0.8938</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>0.8692</td>
<td>0.8269</td>
<td>0.8962</td>
<td>0.9779</td>
<td>0.9087</td>
<td>0.8894</td>
</tr>
<tr>
<td><strong>Specificity</strong></td>
<td>0.9096</td>
<td>0.8192</td>
<td>0.8567</td>
<td>0.9769</td>
<td>0.9077</td>
<td>0.8981</td>
</tr>
<tr>
<td><strong>Precision</strong></td>
<td>0.9058</td>
<td>0.8206</td>
<td>0.8622</td>
<td>0.9769</td>
<td>0.9078</td>
<td>0.8972</td>
</tr>
<tr>
<td><strong>F1 score</strong></td>
<td>0.8871</td>
<td>0.8238</td>
<td>0.8788</td>
<td>0.9774</td>
<td>0.9082</td>
<td>0.8933</td>
</tr>
<tr>
<td><strong>MCC</strong></td>
<td>0.7795</td>
<td>0.6462</td>
<td>0.7535</td>
<td>0.9548</td>
<td>0.8163</td>
<td>0.7875</td>
</tr>
</tbody>
</table>

Supplementary

Tables S1-S5 are not available with this version

Figures
Figure 1

Results of analyzing the intensity change from the thermal image frame of the hand to confirm the feature pattern by water. Hand data of both sides (right: Rt, left: Lt) for the abnormal group (Ab) and the normal group (Nor). The results of WA analyzed for the whole hand area and LA results analyzed locally for the central area of the palm (P) and the second finger (F) are shown. (A) is calculated by obtaining the average intensity change for each thermal image frame and subtracting the value of the first frame from
the value of the corresponding frame. In each dataset, it measures the intensity change as a result of evaporation and diffusion. (B) represents the intensity difference between thermal image frames obtained by subtracting the value of the corresponding frame from the previous frame. As evaporation occurs, the amplitude gradually decreases, and it can be seen that the amplitude changes because of diffusion. For prominent diffusion phenomena, Nor and Ab are indicated by blue and red boxes, respectively.

Figure 2

Temperature difference between the palms of both hands and the endpoints of each finger (2nd, 3rd, and 4th). When the entire hand mask was used as WA for the evaluation of hyperhidrosis, the intensity was calculated from the thermal image frame. The average of the four palms was used. In the case of Nor, the temperature difference was not large, and generally, fingers and palms had similar temperatures. Owing to evaporation, the temperature difference continued to decrease. On the other hand, Ab had a large temperature difference, and it can be seen that it decreased rapidly (WA; whole analysis, Nor; normal group, Ab; abnormal group, Rt; right, Lt; left).
Figure 3

Intensity change data of the three spots extracted from mask images of the 2nd finger and mid-palm of both hands, respectively. When a hand local mask was used as a LA for the evaluation of hyperhidrosis, intensities were obtained and calculated at three locations in the thermal image frame. Evaporation and diffusion at different rates in one local area can be confirmed by intensity change. It can be seen that Ab shows a more rapid change than Nor in the initial stage due to water. The blue box is for Nor, and the red box is for Ab, and it is displayed in the same frame as in Figure 1 where the prominent diffusion phenomenon is shown (LA; local analysis, Nor; normal group, Ab; abnormal group, Rt; right, Lt; left).
Figure 4

**ROC curve for the trained classifier after cross-validation.** K-nearest neighbors showed the best performance, followed by random forest, followed by AdaBoost, ECOC-SVM, discriminant analysis, and decision tree.

Figure 5
**Processing of the thermal image frame for analysis.** The left hand is an image of the abnormal group, and the right hand is an image of the normal group, collected from the same person. (A) After cropping the blank space from the original image, a mask image is created from the thermal image of the back of the hand. (B) The hand mask image was used for the whole analysis. For local analysis, the image of each mask was used after dividing the hand into eight local regions, and the segmented object was identified by labeling. (C) Each mask image was analyzed with the intensity value of the corresponding hand region in addition to each frame. It can be seen that the region to which the heat of the hand is transmitted has high intensity. In this study, a diagnostic evaluation study of hyperhidrosis was conducted using two cases: the analysis data for the whole hand (left) and the data for the local analysis (right). The local analysis result data showed representative areas corresponding to the red arrow (mid-palm and 2nd finger).

**Supplementary Files**

This is a list of supplementary files associated with this preprint. Click to download.

- FigureS1.tif
- FigureS2.tif
- FigureS3.tif
- FigureS4.tif
- FigureS5.tif