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Effects of Changes in Subject and Ambient Surface Temperatures on Discriminating between Normal and Falling Postures Using a Thermal Imaging Sensor

Tomoya Miyasaka, Souta Satomura, Riku Hosoya, Mamiko Kamoshida, Keiko Kawashima

***Abstract*—Some thermal imaging monitoring systems for detecting falls of the elderly use temperature data output by a thermal imaging sensor with discriminant analysis techniques to discriminate between normal and falling postures. This study investigates the effects of subject and ambient temperatures on fall detection based on the results of discriminating between normal and falling postures by changing the subject surface temperature (subject temperature) and the ambient surface temperature (ambient temperature). The subjects were two healthy adults, each in normal and falling postures, whose thermal imaging data were acquired at two subject temperatures and three ambient temperatures. Six discriminant formulae were developed from the acquired data to obtain the discriminant results. The results show that the discrimination rate was 100% for the detection within the temperature range of the data from which the discriminant formulae were developed. In contrast, the discrimination rate decreased for the detection outside the temperature range of the data from which the discriminant formulae were developed. The results indicate that developing discriminant formulae using thermal imaging data in the temperature range of the conditions of use can provide a high discrimination rate between normal and falling postures within that temperature range.**

***Index Terms*— Fall detection, Thermal imaging sensor, Discriminant analysis, Temperature Effects**

I. INTRODUCTION

Falls of elderly facility residents often occur where they are not monitored by a caregiver [1]. This has led to the development of systems that allow caregivers to monitor residents' daily activities and falls from a distance to notify them [2]. A fall detection and monitoring system using a thermal imaging sensor [3] is capable of detecting falls even when a subject person remains motionless unlike the system using a pyroelectric sensor [4]. It also provides an easier privacy-conscious approach than video camera-based systems [5], as thermal images do not directly display facial expressions and skin without blurring themselves. These advantages have led to the development of fall detection and monitoring systems using a thermal imaging sensor that ensure both privacy and early detection of residents' falls in elderly facilities (Fig. 1) [6].

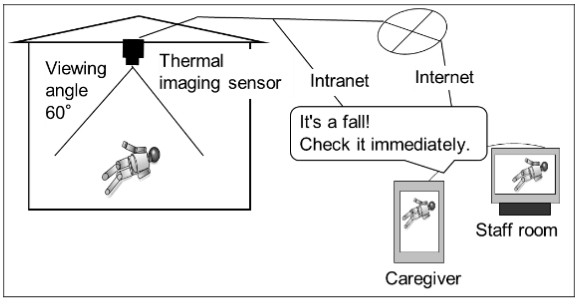

Fig. 1 Falls and monitoring system using thermal image sensor

In a previous study, a method for detecting normal and falling postures using thermal imaging data output from a thermal imaging sensor employed discriminant formulae for detecting between normal and falling postures using thermal imaging data for normal postures labeled as normal and for falling postures labeled as falling [3]. The detection was then carried out by the results of substituting the thermal imaging data to be detected into the developed discriminant formulae. Thermal imaging data were 2256 (47 x 48) temperature values (°C). The method of discriminant analysis [7], one of the inferential statistical methods, was employed to develop the discriminant formulae. Subject (person) and ambient surface temperatures of the data used when developing the discriminant formulae different from those used when performing a discrimination may have led to a different discrimination result.

Previous studies of fall detection and monitoring systems using a thermal imaging sensor include a study on the difference in discrimination rates due to geometric changes of subjects in thermal images depending on the posture and position of people [8] and a study on the posture estimation of falls, etc., using machine learning [9]. However, no reports have mentioned the effects of changes in subject or ambient temperatures. This study compares the discrimination rates when the subject and ambient temperatures change, using discriminant formulae developed with thermal imaging data at a certain subject temperature and a certain ambient temperature, and with discriminant formulae developed with thermal imaging data with a wider range of subject and ambient temperatures. The effects of changes in temperature on fall discriminant rates using thermal imaging data were

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Tomoya Miyasaka, Department of Physical Therapy, Faculty of Health Sciences, Hokkaido University of Science, Sapporo, Hokkaido, Japan.

Souta Satomura, Department of Rehabilitation, Miyanosawa Asuka Hospital, Sapporo, Japan

Riku Hosoya, Department of Rehabilitation, Nishi Sapporo Hospital, Sapporo, Japan

Mamiko Kamoshida, Department of Physical Therapy, Faculty of Health Sciences, Hokkaido University of Science, Sapporo, Hokkaido, Japan.

Keiko Kawashima, Department of Physical Therapy, Faculty of Health Sciences, Hokkaido University of Science, Sapporo, Hokkaido, Japan.

investigated based on the results of the comparison of the discrimination rates.

II. Subjects and Methods

The subjects were two healthy adults. The method involved acquiring thermal imaging data of the subjects in normal and falling postures while changing subject and ambient temperatures. Discriminant formulae were developed to detect between normal and falling postures using the acquired thermal imaging data. The thermal imaging data other than the data used to develop the discriminant formulae were substituted into the developed formulae to detect between normal and falling postures. The percentage of the number of correctly detected data to the number of data used for the discrimination was defined as the discrimination rate.

One subject was chosen for each pair of normal and falling postures. The reason was to eliminate the influence of geometrical configuration due to the body shape of a subject to identify the effect of temperature changes on the discrimination. Two different types of pairs of normal and falling postures were set up, assuming that a resident of a geriatric health services facility performs daily living activities in his/her room [10]. One of those pairs of postures consisted of standing as the normal posture and falling flat as the falling posture, and the other consisted of supine on a bed as the normal posture and falling flat as the falling posture.

The surface temperature of subjects was lowered by layering upper and lower clothing to reduce thermal radiation from their body surfaces [11] to set two temperatures. The ambient temperature was defined as the surface temperature of the floor and walls of the laboratory, and three temperatures were set by adjusting the air conditioning in the laboratory. The discriminant formulae were the one developed using thermal imaging data at one subject temperature and one ambient temperature, and the one developed using thermal imaging data at two subject temperatures and three ambient temperatures. Thermal imaging data to validate the discriminant formulae were generated at two subject temperatures and three ambient temperatures. The data for validating the discriminant formulae were data other than those used to develop the formulae.

This study was carried out in accordance with the Declaration of Helsinki and the "Ethical Guidelines for Medical and Biological Research Involving Human Subjects" of the Japanese Ministry of Health, Labour and Welfare. This study was conducted with ethical considerations, including safeguarding the subjects and obtaining their informed consent after providing explanations. The study plan was reviewed by the Ethics committee in Hokkaido University of Science and approved by the President of Hokkaido University of Science (Approval No. 597).

A. Thermal Imaging Sensor and Experimental System

TP-H0260AN (Chino Co., Tokyo, Japan) (Fig. 2) was used as the thermal imaging sensor. A nursing bed (H = 0.44 m, L = 2.1 m, W = 0.9 m) and the thermal imaging sensor were installed in the laboratory based on the room configuration of a geriatric health services facility as surveyed by the authors (Fig. 3). The thermal imaging sensor was installed at a height of 2.0 m from the floor and 0.3 m away from the nursing bed. The installation angle of the thermal imaging sensor was 45° to the vertical line from the floor.

Fig. 2 Thermal image sensor

Fig. 3 Experimental system

B. Subjects and Collection of Thermal Imaging Data

The subjects were two healthy males in their 20s, subject A and subject B. Subjects A and B were 179 cm tall and 168 cm tall, respectively. Subject A was standing as the normal posture and falling flat as the falling posture. Subject B was supine on the bed as the normal posture and falling flat as the falling posture.

The subjects wore commercial top and bottom long-sleeved underwear as clothing 1, and layers of these and commercial top and bottom sweatshirt/pants as clothing 2. Two surface temperatures near the sternum of the subjects were set. The air conditioning in the laboratory was adjusted to set the ambient temperature at three different levels.

The subjects held each posture for 120 s. For the subjects' postures, 120 thermal images and the corresponding temperature data were acquired using the thermal imaging sensor. Twelve combinations with two different postures, two levels of surface temperature and three levels of ambient temperature per subject were employed. For each of the two subjects, 2,880 thermal images and the corresponding thermal imaging temperature data were acquired.

C. Development and Validation of Discriminant Formulae

Discriminant formulae were developed to detect between normal and falling postures (Fig. 4). Linear discriminant analysis [12] was employed to develop the discriminant formulae. Objective variables labeled as "normal" for thermal imaging data of the normal posture and "fall" for thermal imaging data of the falling posture were employed to develop and validate the discriminant formulae. The 2256 temperature data in the grid of 46 rows by 48 columns in the thermal imaging data were condensed to 552 temperature data in a grid of 23 rows by 24 columns. These condensed temperature data were used as explanatory variables. The acquired data consisted of 120 normal data and 120 falling data each for combinations of two levels of subject temperatures and three levels of ambient temperatures. Those 120 data were divided into 60 data each for developing discriminant formulae and for validating the formulae. The discriminant formulae were polynomials consisting of 552 coefficients and one constant. The temperature values of the data for validation were substituted into the discriminant formulae, determining the posture as normal when the resulting value was negative and falling when positive. The discrimination results were compared with the label of "normal" or "fall," determining the results as "correct" if they matched, and "incorrect" if they did not. The percentage of the number of correctly detected data to the number of data used for the validation was defined as the discrimination rate.

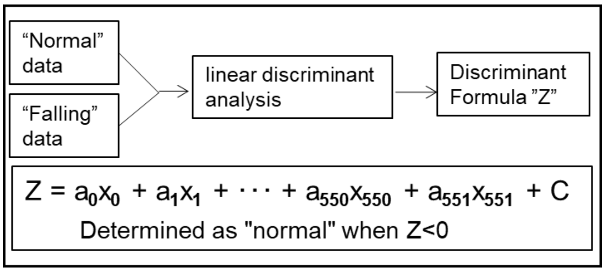

Fig. 4 Discriminant formula

III. Results

A. *Typical Thermal Images and Thermal Imaging Data*

Four typical thermal images acquired by the thermal imaging sensor are shown in Fig. 5. The upper right image in Fig. 5 shows a standing posture of subject A, and the upper left image shows a falling posture. The lower right image in Fig. 5 shows a supine posture on the bed of subject B, and the lower left image shows a falling posture. The subject temperatures were defined as the average surface temperature on the subject's sternum when the subject was in clothing. The average temperature of subject A in clothing 1 was 30°C and that in clothing 2 was 29°C. The average temperature of subject B in clothing 1 was 28°C and that in clothing 2 was 27°C. Three temperatures were set for the ambient surface temperature with air-conditioning settings. Their average temperatures were 22°C, 24°C and 25°C.

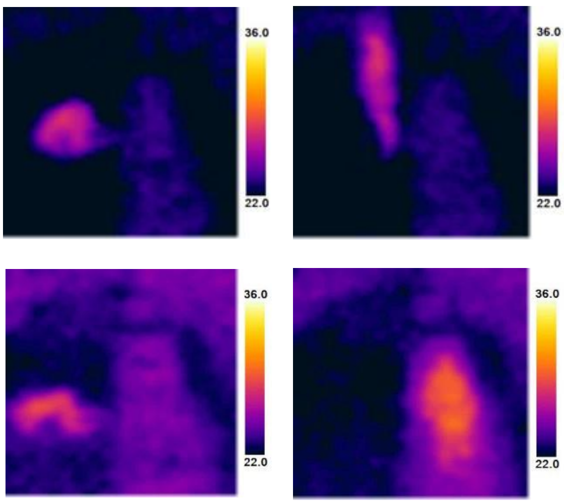

Fig. 5 Typical thermal images

B. *Development and Validation of Discriminant Formulae*

Six datasets were used to develop the discriminant formulae and two datasets for validation (Fig. 6). The discriminant formulae 1-4 were developed with a total of 20 data of 10 data each of normal and falling data at one level of the subject temperature for each subject and one level of ambient temperature of 24°C. The discriminant formulae 5 and 6 were developed with a total of 120 data of 10 data each of normal and falling data at two levels of the subject temperature for each subject and three levels of the ambient temperature.

Data set	Subjects	Subject surface temp.(℃)	Ambient surface temp.(℃)	Normal posture	Falling posture	Number of data
Dataset for creating a discriminant formula						
1	A	30	24	Standing	Falling flat	Normai;10 Falling;10
2		29				
3	B	28		Supine		
4		27				
5	A	29,30	22,24,25	Standing		Normal;60 Falling;60
6	B	27,28		Supine		
Dataset for validating the discriminant formulas						
1	A	29,30	22,24,25	Standing	Falling flat	Normal;60 Falling;60
2	B	27,28	22,24,25	Supine		

Fig. 6 Dataset for Discriminant Equation Creation and Validation

The coefficients of the six discriminant formulae developed are shown in a two-dimensional arrangement (Fig. 7). The top 25% of the highest coefficients are shown in red, the bottom 25% in blue, and the middle 50% in orange for positive and zero, and light blue for negative. The coefficients for the discriminant formulae 1-4 had values of 0.03 or higher and lower than 0.19 for red, 0 or higher and lower than 0.03 for orange, -0.02 or higher and lower than 0 for light blue, and -0.13 or higher and lower than -0.02 for blue. The coefficients for the discriminant formulae 5 and 6 had values of 0.08 or higher and lower than 0.48 for red, 0 or higher and lower than 0.08 for orange, -0.08 or higher and lower than 0 for light blue, and -0.43 or higher and lower than -0.08 for blue.

Validation of the discriminant formulae was carried out by substituting the data for validation. Two sets of data for validation were prepared for each of the two subjects. The data for validation 1 were a total of 120 data of 10 data each of normal and falling posture data at two levels of the subject temperature for subject A and three levels of the ambient temperature. The data for validation 2 were for subject B, with the same number and combination of data as for the data for validation 1.

The validation results of the discriminant formulae 1-4 are shown in Table 1. The validation result 1 was obtained by substituting the data for validation 1 into the discriminant formula 1, which was developed using data for subject A with a subject temperature of 30°C and an ambient temperature of 24°C. The validation result 2 was obtained by substituting the data for validation 1 into the discriminant formula 2, which was developed using data for subject A with a subject

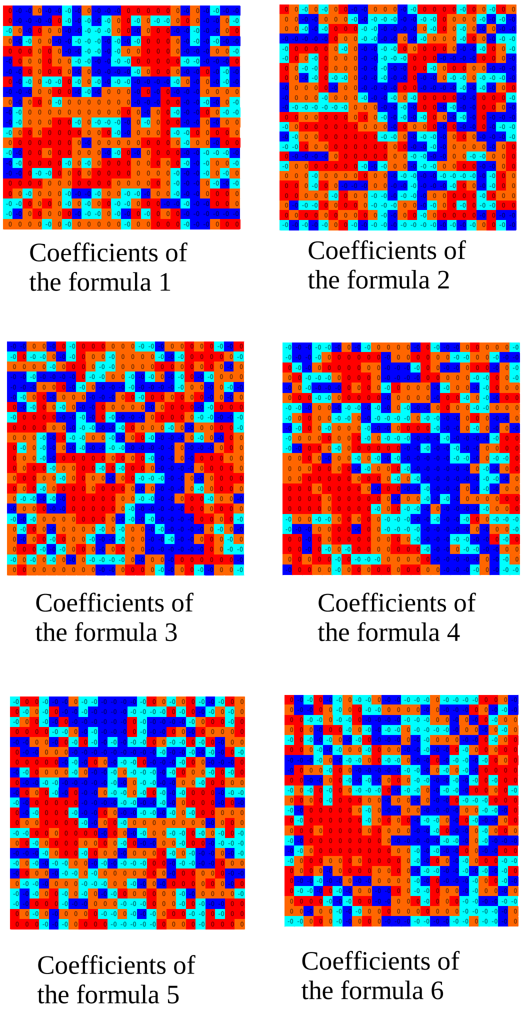

Fig. 7 Discriminant formula coefficients arranged in two dimensions

temperature of 29°C and an ambient temperature of 24°C. The validation result 3 was obtained by substituting the data for validation 2 into the discriminant formula 3, which was developed using data for subject B with a subject temperature of 28°C and an ambient temperature of 24°C. The validation result 4 was obtained by substituting the data for validation 2 into the discriminant formula 4, which was developed using data for subject B with a subject temperature of 27°C and an ambient temperature of 24°C.

The validation results of the discriminant formulae 5 and 6 are shown in Table 2. The validation result 5 was obtained by substituting the data for validation 1 into the discriminant formula 5, which was developed using data for subject A with subject temperatures of 29°C and 30°C, and ambient temperatures of 22°C, 24°C and 25°C. The validation result 6 was obtained by substituting the data for validation 2 into the discriminant formula 6, which was developed using data for subject B with subject temperatures of 27°C and 28°C, and ambient temperatures of 22°C, 24°C and 25°C.

In both Tables 1 and 2, incorrectly detected cases for a normal posture as a falling posture were tabulated as X1. Incorrectly detected cases for a falling posture as a normal posture were tabulated as X2. Blank cells in the tables indicate that all 10 data were correctly detected. Cells with a white background in the table represent the validation results within the range of explanatory variables of the discriminant formula, while cells with a gray background outside the range. The percentage of the number of correctly detected data to the total number of data for validation was defined as the discrimination rate.

Table 1 Results of validation of discriminant formulas 1-4

Validation result 1, Subject A			
℃	22	24	25
29	X1 X2(10/10)	X1 X2	X1(10/10) X2
30	X1 X2(10/10)	X1 X2	X1(10/10) X2

Validation result 2, Subject A			
℃	22	24	25
29	X1 X2	X1 X2	X1 X2
30	X1 X2	X1 X2	X1 X2

Validation result 3, Subject B			
℃	22	24	25
27	X1 X2(10/10)	X1(10/10) X2	X1(10/10) X2
28	X1 X2(5/10)	X1 X2	X1(10/10) X2

Validation result 4, Subject B			
℃	22	24	25
27	X1 X2	X1 X2	X1 X2
28	X1 X2	X1 X2	X1 X2

Table 2 Results of validation of discriminant formulas 5,6

Validation result 5, Subject A			
℃	22	24	25
29	X1 X2	X1 X2	X1 X2
30	X1 X2	X1 X2	X1 X2

Validation result 6, Subject B			
℃	22	24	25
27	X1 X2	X1 X2	X1 X2
28	X1 X2	X1 X2	X1 X2

C. Validation Results of the Discriminant Formulae for the Range of One Subject Temperature and One Ambient Temperature

Validation results 1 and 2 were obtained with subject A. The discrimination rate of 20 data with a subject temperature of 30°C and an ambient temperature of 24°C, which were within the same temperature range as the discriminant formula 1, was 100% in the validation result 1. In contrast, the discrimination rate was 66.7% for 120 data in a temperature range of two subject temperatures and three ambient temperatures, with 80 data being correctly detected. Of the 40 incorrectly detected data, X1 was 20 data with an ambient temperature of 25°C, and X2 was 20 data with an ambient temperature of 22°C. The discrimination rate of 20 data with a subject temperature of 29°C and an ambient temperature of 24°C, which were within the same temperature range as the discriminant formula 2, was 100% in the validation result 2. The discrimination rate was 100% for 120 data in a temperature range of two subject temperatures and three ambient temperatures.

Validation results 3 and 4 were obtained with subject B. The discrimination rate of 20 data with a subject temperature of 28°C and an ambient temperature of 24°C, which were within the same temperature range as the discriminant formula 3, was 100% in the validation result 3. In contrast, the discrimination rate was 62.5% for 120 data in a temperature range of two subject temperatures and three ambient temperatures, with 75 data being correctly detected. Of the 45 incorrectly detected data, X1 was 30 data consisting of 20 data with subject temperatures of 27°C and 28°C and an ambient temperature of 25°C, and 10 data with a subject temperature of 27°C and an ambient temperature of 24°C. X2 was 15 data with subject temperatures of 27°C and 28°C and an ambient temperature of 22°C. The discrimination rate of 20 data with a subject temperature of 27°C and an ambient temperature of 24°C, which were within the same temperature range as the discriminant formula 4, was 100% in the validation result 4. The discrimination rate was 100% for 120 data in a temperature range of two subject temperatures and three ambient temperatures.

D. Validation Results of the Discriminant Formulae for the Range of Two Subject Temperatures and Three Ambient Temperatures

The discrimination rate of 120 data in a temperature range of two subject temperatures and three ambient temperatures, which were within the same temperature ranges as the discriminant formulae, was 100% for both the validation result 5 with subject A and the validation result 6 with subject B.

IV. Discussion

A. Method of Discrimination

The discrimination between normal and falling postures was based on the method of linear discriminant analysis [12]. Discriminant formulae were developed with 552 temperature values averaged from thermal imaging data as explanatory variables and labels for normal and falling postures as objective variables. The temperature values of the data for validation were substituted into the developed discriminant formulae, determining the posture as normal when the result was negative, and falling when positive (Fig. 4). The coefficients of the six discriminant formulae arranged two-dimensionally (Fig. 7) show a distribution of high positive coefficients in the positions representing the falling flat posture in the thermal image. The coefficients of the discriminant formulae 1, 2 and 5 arranged two-dimensionally show a distribution of high negative coefficients in the positions representing the head to scapular regions in the standing posture in the thermal image. The coefficients of the discriminant formulae 3, 4 and 6 arranged two-dimensionally show a distribution of high negative coefficients in the positions representing the supine posture on the bed in the thermal image. The above results show that a subject (high-temperature range) being in the range of positive coefficients of a discriminant formula tends to be determined as falling, whereas an ambient temperature (low-temperature range) being in the range as normal. They also show that a subject (high-temperature range) being in the range of negative coefficients of a discriminant formula tends to be determined as normal, whereas an ambient temperature (low-temperature range) being in the range as falling.

B. Validation Results of the Discriminant Formulae

The discrimination rates for validation results 1-4 were 100% within the range of temperature data used to develop the discriminant formulae. In discriminant formulae using linear discriminant analysis, the coefficients of the formulae are determined so that objective variables can be best separated within the range of explanatory variables [11]. This led to a high discrimination rate within the range of subject and ambient temperatures for the data used to develop the discriminant formulae. The discrimination rates for validation results 5 and 6 were 100% within the range of 2°C wider for two subject temperatures and 4°C wider for three ambient temperatures in the development of the discriminant formulae. These discriminant formulae showed that even when the range of explanatory variables is widened, they provide a high discrimination rate within the range of the explanatory variables. The results of the discrimination rates for validation results 1-4 and the results of the discrimination rates for validation results 5 and 6 show that the discrimination is correct within the range of the explanatory variables of the discriminant formulae, whereas the discrimination can be incorrect outside the range of the explanatory variables.

V. Summary

The subjects were two healthy adults, thermal imaging data were acquired by changing the subject and ambient temperatures, and discriminant formulae were developed using linear discriminant analysis to discriminate between normal and falling postures. The validation results of the discriminant formulae showed that the discrimination was correct within the temperature range of explanatory variables in the discriminant formulae but incorrect outside the range. For discriminant analysis using thermal imaging data, developing a discriminant formula with a temperature range of subject and ambient temperatures that matches the conditions at the time of discrimination can be concluded to be effective. In the future, discriminant formulae reflecting the range of subject and ambient temperatures will be developed in actual elderly facilities to validate the ability to detect between normal and falling postures.

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