DEVELOPMENT OF A PAIN EVALUATION SYSTEM BY IMAGE ANALYSIS OF FACIAL EXPRESSION

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ABSTRACT
In the field of nursing care for the elderly, understanding their somatic sensations, such as pain, is very important for caregivers to be able to provide appropriate care. However, it is not always easy for caregivers to understand such somatic sensations of an elderly person with declining verbal function. Therefore, an objective evaluation method of pain intensity without verbal communication is required. In this study, a pain evaluation system was developed for use in a daily life where verbal communication is not possible. This system is noninvasive because the information corresponding to pain intensity is extracted from facial expressions. In order to digitize the facial expressions, images of faces were extracted from a video at a regular time interval and were analyzed sequentially. A pain stimulation test where healthy adult subjects dipped their hands into ice water was carried out. A strong correlation between pain face factor calculated from the facial expressions digitized by the system and sensory evaluation shown by a pain score, VAS value, was observed for young adults. It indicates the validity of this system for estimation of pain intensity.

KEY WORDS
Facial expression, Pain, Image analysis

1. Introduction
In the field of nursing care for the elderly, understanding their somatic sensations, particularly pain, is very important for appropriate care. Somatic sensations include the sense of pain, pressure, cold and warmth. Among them, to understand the sense of pain is one of the most important to maintain QOL (Quality of life) for the elderly. However, qualitative and objective evaluation methods of somatic sensation, including pain, have not been established yet. Generally, verbal communication is used when the elderly let others know that they are in pain, but a non-verbal communication method is required when their verbal functions are impaired. There are several methods of evaluating the pain, such as the McGill pain questionnaire (MPQ), the visual analogue scale (VAS), the numerical rating scale (NRS), the verbal rating scale (VRS), and the faces pain scale (FRS), but these methods are based on the response from the subject, even though it is not always easy for the subjects to give one, depending on their physical condition. In addition, when the caregiver checks the degree of pain an elderly person feels from their behavior, such as facial expressions, the direction of the eyes, or posture, it is not objective because judgment depends on the caregivers. Pain intensity can be also presumed with biological signals, such as an electrocardiogram (EKG) and an electroencephalogram (EEG). Both equipments are getting smaller but EEG has not become a potable size yet and requires the placing of electrodes on the chest or head, which is not quite practical. Although further research of contactless ECG and downsizing of EEG is being carried out, they have not been completed yet. Furthermore, operating the equipment and analyzing the data require specialized knowledge, which makes it difficult to apply to common use. Hence, it seems that the use of a simpler system for surveillance of people without the need of such sophisticated equipment is ideal both economically and practically in the case of pain analysis, especially at home.

The advantage of facial expression analysis is that it gives a lot of information with a simple, noninvasive method. A typical facial analysis method is called a facial action coding system (FACS). This method uses coded data obtained by a combination of the minimum unit of facial motions called Action Units (AU). With this method, time-series data can be analyzed objectively, but the output is affected by the subjective-view of the FACS coder. This means that the disadvantage of this system is the necessity of FACS coders training and the time it takes to analyze the data. Hence, a system for pain estimation based on FACS for use in a daily life where verbal communication is not possible has been developed.

A program for a pain evaluation system using image analysis of facial expressions was built as a prototype from past basic study. The program required an even higher practical utility in order to use it in an actual life. The program progressed in the accuracy of its face tracking and capturing system, moreover it can evaluate in real time.
2 Facial Analysis Method

2.1 Digitization of Facial Expressions

Facial expressions were digitized as a matrix to estimate pain quantitatively by facial analysis. Changes in facial expression from the standard were converted as \([X_1 \times X_2 \ldots X_9]^T[F_1 F_2 \ldots F_9]\). This equation, \([F_1 F_2 \ldots F_9]\) is a matrix which indicates changes in each part of the face; for example, \(F_1\) indicates “right brow raised” and \(F_9\) indicates “mouth open” as shown in Figure 1 and Table 1.

\[
1: \text{There was a facial change indicated by } F_i \\
X_i = 0: \text{There was no facial change indicated by } F_i \\
-1: \text{There was an opposite change indicated by } F_i
\] (1)

Table 1. Analyzed parts of the face

<table>
<thead>
<tr>
<th>Code</th>
<th>The changes on parts of the face</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1, F2</td>
<td>raising eye brow (right &amp; left)</td>
</tr>
<tr>
<td>F3, F4</td>
<td>opening eyes (right &amp; left)</td>
</tr>
<tr>
<td>F6, F8</td>
<td>raising corner of mouth (right &amp; left)</td>
</tr>
<tr>
<td>F5, F7</td>
<td>stretching corner of mouth (right &amp; left)</td>
</tr>
<tr>
<td>F9</td>
<td>mouth open</td>
</tr>
</tbody>
</table>

For example, based on this method, for example, a face in which both brows were lowered (\(X_1 = -1, X_2 = -1\)), both eyes were closed (\(X_3 = -1, X_4 = -1\)), both corners of the mouth were raised (\(X_7 = 1, X_8 = 1\)), and the mouth was open was digitized as \([-1 -1 -1 0 1 0 1 1]\)^T[F_1 F_2 \ldots F_9].

Eq. 2 was defined with a digitized matrix of facial expressions, where (A) is the target face matrix, (B) is the pain face factor and (C) is the pain face matrix.

\[
\begin{bmatrix} A \\ B \end{bmatrix} = \begin{bmatrix} X_1 X_2 \ldots X_9 \end{bmatrix}^T \begin{bmatrix} F_1 F_2 \ldots F_9 \end{bmatrix}
\]

\[
A = \text{Determinant of objective facial expression analysis} \\
B = \text{Pain facial expression coefficient} \\
C = \text{Determinant of pain facial expression}
\]

This equation shows that the target face matrix (A) was a linear coupling of the pain face factor (B) and the pain face matrix (C). The pain matrix (C) was determined from a preparatory experiment, in which photos were taken of the facial expressions of six male subjects with pain stimulation, and their common features were extracted from the pain face. The pain face factor (B) was calculated by substituting the target face matrix into (A) in Eq. 2.

The program calculates the movement of parts of the face and evaluates facial pain expressions automatically. The program operates in C++ language with an application called FaceAPI (Application Program Interface) by Seeing Machines Ltd., that utilizes OpenCV. FaceAPI can estimate the coordinates of facial benchmark distance between the eye brows and retrieve data in specific seconds. (5 frames/sec in this experiment) The program was activated using the above equations (1) and (2).

3. Image Analysis of Pain Faces

3.1 Purpose of experiment

The pain face factor was evaluated by analyzing the facial expressions of the subjects when they put their hand into ice water. The pain face factor was compared with the value of sensory evaluation conducted at the end of each set of experiments, and the validity of the facial analysis method was evaluated. (see Figure 3)
3.2 Subjects

Ten healthy young subjects (six females and four males) participated in this experiment. None of them were suffering from chronic pain. The subjects heard the explanation about the objective and the protocol of this experiment, and were informed that they would be able to stop whenever they felt extreme pain. Written consent was obtained from the subjects after they had been sufficiently informed.

3.3 Procedure of the Experiment

Although it is hard to meet all the condition of pain stimulus test which are defined by some researchers, a couple of candidate methods, such as the cold pressor test and electrical stimulus test, were selected. Eventually, the cold pressor test was selected due to its cost and practicality.

Spanson, Johnson and Horner 1983 pointed to the limitation of using this experiment by describing the decline of feeling caused by acclimatizing and freezing. Also, Tanaka 1989 said that generally such an experiment is effective within 5 minutes, even if there is variation between individuals. According to these indications, the experiment was carefully carried out.

In order to stabilize the temperature of the water to obtain reproducible measurement condition without any special device, iced water was prepared. The experiment of pain evaluation by the cold pressor test was carried out by many researchers such as Boucher 1969, Hentschel 1999, Craig KD 1985 and Shimazu 2001.

The subjects sat and dipped their hand in to ice water. The camera began recording their face just before subject’s hand went into the water. Three video cameras were set at a one meter distance from the subject, one built in webcam in the middle and two others set to both sides of the subject at a specific angle. Their facial expressions were continually monitored with those cameras and the image data was converted to log data. Therefore, the privacy of the subjects is protected.

During the experiment, a sensory evaluation was also conducted by self-assessment using the VAS (Visual Analog Scale) method. The index of pain was defined as 0 (no pain) to 10 (maximum imaginable pain). The subject checks the marker as soon as he has finished with each set of experiments. The position of the marker was obtained by image analysis to estimate VAS value. Every subject tried three sets of experiments and two optional sets. (see Figure 4)

3.4 Analytical procedure and result

The pain face factor was evaluated from captured facial images, and VAS value was evaluated by the position of the marker. The validity of pain evaluation from facial expression was considered by evaluating the correlation between the pain face factor and the VAS value. As an exploratory experiment, five photos were taken a month of each subject and five facial images were synthesized and defined as a standard face.

The evaluation score of the facial expression was calculated from collected log data and the numerical value of the pain facial expression coefficient in each set captured by center front webcam was calculated. The VAS value was calculated by the VAS method and the validity of the pain evaluation using the pain expression coefficient was examined by evaluating the correlation between both data.

The mean value of the final data of ten frames (two seconds) for each set was used for correlation with the VAS value. A facial pain expression coefficient and the VAS value that were obtained from this program are indicated in Figure 5 and Figure 6 also shows the relation between a facial pain expression coefficient and the VAS value. The correlation of r=0.83 on average was shown.
between a pain facial expression coefficient and the VAS value. As a result, the program verified the validity of the evaluation system of facial pain expression.

3.5 Comparing between age groups

The system has been validated over young people although the final targets are the elderly people. However, Kunz, M 2008 justified this issue. The consequence of this paper was summarized as follows; the age had no significant impact on the pain specificity of these facial responses. As well as this, both age groups (40 young: mean age, 24.1 years and 61 elderly: mean age, 72.3 years) experienced comparable amounts of pain intensities. Therefore, the elderly individuals seem to communicate pain through their facial expressions in a similar way as younger individuals.

Elderly face capturing accuracy was examined horizontally and vertically. Ten healthy elderly subjects (age 64 up to 88: average 71.7) participated in this experiment. The procedure of informed consent was properly conducted. The results of this experiment showed, the accuracy of face capturing seemed to be slightly weaker than with younger subjects.

Thus, compared to a younger person’s face, an elderly individual’s face has wrinkles which might lead to the decline of face capturing accuracy. Hence, increasing the accuracy of elderly face capturing is required. The detail of this difference is under investigation.

4. Verification of Diagonal Face Capturing

4.1 Capacity of capturing angle

Although the validity of the pain evaluation by this method was confirmed from the experiment, the program is required to show practical utility, which is facial analysis by diagonal capturing data.

First of all, the functional limit of the angle of the subject’s head was verified before hand using data from the subject shaking head without any expression twenty times at each angle (20 degree 30 degree 40 degree 50 degree).

As Figure 7 shows, mirrors were set at each angle and subjects shook their heads until their face came to the center of the mirror. Also, as Figure 8 shows, the experiment was carried out using a doll head to measure the correct angle. The doll test was performed not only to verify human data as well as doll data, but to replace the dimensionless value of the head angle from the FaceAPI with a real angle.
The following is the result of the F-test in each angle between the human and the doll: 20 degree $P (F<=f)$ one side $0.10053$, 30 degree $P (F<=f)$ one side $0.45731$, 40 degree $P (F<=f)$ one side $0.05542$, 50 degree $P (F<=f)$ one side $1.53E08$. Although the accuracy capturing the output data for the doll test was considerably more stable even at 50 degree (SD 1.589), the captured data from the human head was unstable so that the F-value at 50 degree was poor.

Secondly, the results of the T-test between the human head and the doll was verified. As Table2 shows, a shaking head within 45 degree on both sides was regarded as the same data. Not to mention, the T-test at 50 degree went unadministered because of the results of the F-value.

Figure 9 is an example of output data from FaceAPI, a positive value describes turning the head left and negative is the opposite. Figure 10 is around the peak point in Figure 9. Above analyses were used as data for these peak points. It can be seen in Table 2, that the stability of reproducibility decreased when the head angle widened. Judging by the results of these experiments, 45 degree is the functional limit of capturing facial expressions at the moment, hence the analysis of facial expression is valid within 45 degree, as Figure 11 shows.

<table>
<thead>
<tr>
<th>Head Angle</th>
<th>T-value</th>
<th>Standard Deviation</th>
</tr>
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<tbody>
<tr>
<td>20 degree</td>
<td>1.76</td>
<td>0.59</td>
</tr>
<tr>
<td>30 degree</td>
<td>0.26</td>
<td>0.85</td>
</tr>
<tr>
<td>40 degree</td>
<td>0.01</td>
<td>1.025</td>
</tr>
<tr>
<td>45 degree</td>
<td>0.77</td>
<td>1.39</td>
</tr>
</tbody>
</table>

4.2 Verification of diagonal facial expression capture

The program verified the validity of the evaluation system of facial pain expression as stated in section 3. The functional limit for capturing the face angle was verified within 45 degree on both sides in section 4-1.

Next, the program verified the facial pain evaluation system within 45 degree. Facial pain expression data was captured from three angles. Eight subjects were selected out of ten and groups of two subjects had their
expressions captured in each direction, such as 20 degree 30 degree 40 degree 45 degree as illustrated in Figure 12. Although the functional limit for capturing was verified within 45 degree on both sides, the accuracy of pain evaluation was even narrower than 45 degree. The coefficient of correlation at 45 degree was r=5.289. As a result of all the experimentation and validation, the program can capture and evaluate facial pain expression within 30 degree on both sides.

Rapid decline of the output accuracy at 30 degree indicates that this is not totally related the angle of face. For example, Figure 13 shows a sudden data change at a specific angle. Therefore, the accuracy of the program will be enhanced by closely examining the pattern of data turbulence in the future.

4.3 Face capturing accuracy of vertical angle

The program was verified about horizontal angles of face so far. However, in order to show further practical utility, the program should also look at capturing the vertical angles of a face as well. In fact, the program exposed the weakness of the capturing accuracy at functional limit of this angle, especially downwards. The data noise appeared around 5 degree downwards. On the other hand, upward was better than downward and relatively clear and stable data appeared, up until around 15 degree. Therefore, it seems that the evaluation of facial expressions is quite hard with this program at the moment.

However, presumably, the elimination of noise at an upward angle will be able to be solved because the data of eyebrows are related to the vertical angle of a face. Some other capturing points, such as rip points, are not totally related by head angles, but the data shows sudden data changes between specific angles are stable enough to measure. Therefore, it seems that the range of detectable angles of facial analysis upward is up to 30 degree even if the accuracy of output data decreases when the face angle becomes steeper.

A possible reason for this problem is that basic face points of evaluation are calculated using vertical shifting, so that many capturing points are affected by vertical movement of the face. As well as this, it may say that vertical movement of the face is affected by brightness, so that the accuracy of face capturing for downward movement is considerably weak.

If the method of the experiment is further reviewed, then the program will be able to analyze all directions of face angles in the future.

5. Conclusion

A noninvasive and no-contact system of pain estimation using facial expression for use in a daily life where verbal communication is not possible has been developed. A strong correlation was observed for young adults between the pain face factor calculated from the facial expression digitized by the system and the sensory evaluation score of pain, VAS value. Also the results show that diagonal face capturing and evaluating facial expressions with in 30 degree has satisfactory accuracy. However, the program needs to track the up and down movement of the face as well. Then facial movement can be captured in any direction. Face tracking systems can be used for operating analysis, so the program will be able to analyze several things with one output in the future.

This indicates the validity of this system for estimating pain intensity where there can be no verbal communication. The system is currently being improved for application in a variety of age brackets, particularly the elderly, who have facial expressions much different from young adults. Furthermore, the practical application in the field of nursing care will be considered based on the results.
References