Non – Clinical Pain Assessment System – A Pilot Study

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Abstract. The term ‘Pain’ refers to the sensory response of the body when the reflex tolerance level of the person exceeds the threshold value. Though most of the pain senses are tolerable, it still disturbs the normal anatomical actions of the body, classifying it as tolerable and intolerable pain. Various techniques have evolved in the past few years to quantify pain; however, they are successful only in subjective determination thus leading to inaccuracy in prediction. The proposed paper discusses a few objective methods to quantify non–clinical pain. FLIR spectroscopic images can recognize inflammation and high-temperature points in a given region. Upon using various mechanical algorithms, accurate pain values can be determined. Similarly, by solving the pain-causing equation, we can derive the pain peak values. These methods can replace the conventional scales and help in subsidiary pain assessment.

1. Introduction

The human body is composed of various biosignals which are used to study the diseases corresponding to the organs. However, any disturbance that comes as compensation is claimed as pain, and the body ejects out a sensory response that is difficult to acquire by normal acquisition systems. The International Association for the Study of Pain (IASP) classifies pain into two types:[1][2]

- Clinical pain: They constitute the sensory response due to internal factors like chronic diseases and automatic body stimuli. The glandular response of such a pain is usually high.
- Non – clinical pain: They constitute the sensory response due to external factors like wounds, heat burns, and injuries. The glandular response of such a pain is usually low.

The pain signals can be acquired using nerve excitation systems but they require a high level of amplification and sensory network array which makes the device complex. Pain measurement is essential for the following [3]

- Tracking the progress of the patient towards the disease
- To promote the right levels of drug dosage
- For diagnosis of affirmative diseases (Diseases that require continuous predictions)
2. Existing methods and their limitations

2.1 Conventional scales
To determine the strength of the pain, various scales like the Numerical rating scale, visual analog scale, Behavioral pain scales, etc. were developed. However, all these scales are based on the patient’s response (subjective). Since different persons have a different tolerance level, for the same injury, the pain experienced by 2 different patients is not the same. Thus, conventional scales weren’t proved to be an accurate technique to analyze pain [4]. These scales are ranked from 1 to 10 or 1 to 25 with a lower number being less pain and a higher number being the most pain value.

2.2 Dolorimeter
To replace the inaccuracy in the pain scale, a pressure-based system was developed called the dolorimeter [5][10] where the knob of the system will be pinched into the pain region. The point at which the patient experiences additional pain is taken as the pain value and the unit of measurement is dels or dol. However, since pain origination is not taken into consideration, the meter produces inaccurate results. Another major limitation includes calibration. The meter scales generally drop down in the middle leading to false prediction.

2.3 Machine learning algorithms
Machine learning and AI-based algorithms were developed to recognize the patient’s emotions and face expressions and correspond them to the appropriate pain rank in the scales. Though GUIs are developed a lot for this process, emotion recognition turned out to be an iterative technique and hence did not produce accurate results [8][9]. This technique was similar to conventional behavioural scales and led to the development of facial expression recognition and face angular identity to equalize them with the pain rank.

2.4 fMRI method
Functional magnetic resonance imaging is similar to magnetic resonance imaging which predicts small changes in blood flow in the brain. Since all the reflex sensory actions are sent to the brain for response and processing, the pain signals are equated with EEG [11][12]. However, the cost and origination of pain is a concern.

2.5 Theory of proposed solution
To overcome the limitations of the dolorimeter, invasive techniques [13] were developed like electrical stimulation and nerve excitation. Since the sensory response is of a low amplitude signal, it is difficult to acquire, and filtering leads to loss of the signal. The proposed solution uses ordinary differential equations and FLIR spectroscopy images to determine results. Non-clinical pain is accompanied by other immune responses like inflammation and high temperature [6], upon identifying those regions, we can derive the pain values. This operation includes the triangulation of FLIR spectroscopic images and centroid plotting. Similarly, every pain-causing agent will be equated with an ordinary differential equation. Upon solving the equations, we can acquire pain value.

3. System architecture and Data Collection
The following figure briefly describes the system flow and the processes involved in pain assessment.
3.1. Data collection
The data is collected from the International spinal cord society [15] where the data is related to heat burns and other external stimuli. The equation for the corresponding data values is derived from Hill’s model and the equation is as follows [7]. The equations are produced due to effector muscle response which is captured using a relay.

4. Method 1 – FLIR Image analysis
FLIR images are multi-coloured images that signify the amount of infrared radiations the object has reflected and transmitted. A FLIR capturing camera involves several algorithms to interpret data and
compares the environmental temperature with the captured object’s temperature. This measurand is compared with the standard value to determine the actual value.

The equation is [7]

\[
\text{Incident Radiant} = \text{Emitted Radiant} + \text{Transmitted Radiant} + \text{Reflected Radiant}
\]

Eqn.01

A thermogram is an imaging modality that is used to identify high-temperature ranges and inflammation points [14]. The proposed method uses FLIR thermograms to find the regions or points at which the pain originates or persists.

4.1 Image processing

The three coloured images are processed by

- Converting images to grayscale and resizing
- Removing Gaussian noise from the images using appropriate filters
- Applying triangulation to make the image’s centroid supported.

The image collected corresponds to a person with burns in the chest region

![Figure 3. Original image](image1)

![Figure 4. Intermediate image](image2)

![Figure 5. Processed image](image3)

In the next step, the processed image will be segmented into micro-units called blobs to make the analysis much easier. Lattice mapping (High-temperature regions are marked using the Lattice algorithm) is applied to the images to plot the location of high temperature. Blob mapping is applied...
on images (Inflammatory regions are mapped using Blob algorithm) to locate the location of inflammatory points. Interpolation is done to the three brightest dimes (units of blobs) to predict the accuracy of the analysis.

**Figure 7.** Processed images

Figure 7 shows the lattice mapping followed by blob mapping, blob segmentation and segmented regions consecutively. The time taken for the entire analysis to complete is about 60 seconds (elapsed time). This is much lesser compared to conventional thermal imaging techniques. Using Radon transform, the temperature in Fahrenheit and the inflammation strength in dimes is determined for all the points in the region of interest. Apart from these, we determine other parameters such as:

- **Aff**: This value represents the error in locating the accurate coordinate of a target (either temperature or the inflammatory point)
- **F-bend**: This value represents the lattice cofactor at each point in the region of interest considered. It helps in further processing the images based on the ROI segmented.
- **F-angle**: This value represents the Blob co-factor at each point in the region of interest considered. It helps in further processing the images based on the blobs segmented.
- **Centroid**: This value represents the coordinates at which the centroids are plotted at each point in the image.

**Table 1.** Command window showing various parameter values

| Blob # | Temperature (in F) | Aff   | F-bend  | F-angle | Centroid | Inflammation |
|--------|--------------------|-------|---------|---------|----------|--------------|
| #1     | 102.3              | 11112.0 | 1371.4 | 48.7    | 134.0    | 118.9        |
| #2     | 102.0              | 42.0   | 35.1    | 4.9     | 114.3    | 7.3          |
| #3     | 101.4              | 16.0   | 19.6    | 2.1     | 124.1    | 4.5          |
| #4     | 102.0              | 2.0    | 2.0     | 1.5     | 136.0    | 1.6          |
| #5     | 101.1              | 9.0    | 12.8    | 2.9     | 139.6    | 3.4          |
| #6     | 102.6              | 25.0   | 26.5    | 1.9     | 148.2    | 5.6          |
| #7     | 102.1              | 7.0    | 6.8     | 2.1     | 157.7    | 3.0          |
| #8     | 102.0              | 1.0    | 0.0     | 1.0     | 185.0    | 1.1          |
The triangulation plot helps in plotting the real-time data obtained in a lattice space which can further be used to derive standard threshold and measurand threshold.

4.2 Centroid plotting
The temperature and inflammation points collected correspond to many points in the image. However, to acquire one final pain point, centroid plotting is important. This is done using a radon transform.
The above equation is a sub derivation of Hill’s equations [8] where the pain value is the subtractive index of 10th dividend of X and Y coordinate values.

5. Method 2 – ODE Analysis

The Hill’s equation corresponding to heat stimulus[8] defines the reflex actions to a corresponding stimuli like heat or needle incision. The corresponding heat equation is given below where a to c are Limerick’s constants, V is the stimuli voltage,

\[
A1(n) = \frac{\left(\frac{a}{c}\right) \times (V(n))^3 + \left(\frac{b}{c}\right) \times (V(n))^2 + \left(\frac{dV}{c}\right) \times V(n) + \left(\frac{d1}{c}\right) \times I1(n) + (\text{Asin}2\pi mh \times (F + K))}{c}
\]

On solving this nth order equation, we get n number of solutions which are again factorized to n number of linear equations. This gives us an accurate pain value along with the parametric value chosen.
The One–way ANOVA table can be used to indicate the error in the plot either column wise or row wise [17]. The above ANOVA table represents the error in all the points of space lattice column-wise and plots the error and mean sum of the data collected. The ANOVA stats and P-value are displayed as default in an ANOVA test determining the level of significance.

| Source    | Space lattice | Degree of freedom | Mean Sum         | Stats   | Prob>F (P-value) |
|-----------|---------------|-------------------|------------------|---------|-----------------|
| Columns   | 3.46921e+09   | 2                 | 1.7346e+09       | 710.27  | 2.022e-293      |
| Error     | 3.16284e+10   | 12951             | 2.44216e+06      |         |                 |
| Total     | 3.50976e+10   | 12953             |                  |         |                 |

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**Table 3. Acquired pain value = 1.88**

| Command window |
|----------------|
| **Trial 1 – 1.0e+04** |
| Parametric factor -1 | Pain value | Parametric factor -2 |
| 0.9882 | 1.8833 | 0.6584 |
6. Discussion

Database of patients with burns was collected and mapped for the regions of inflammations and temperature points. Other parameters evaluated like Fangle, Fbend and aff were used in angularity measurements. Overall centroid plot was mapped to get the pain point at maximum inflammation and temperature points. The acquired pain was around 4.8. Ordinary differential equations corresponding to stimuli were derived and solved to get solutions that were exposed to the H-step and factorization to get the required pain value. The pain value acquired was around 1.8 for spinal cord injury databases. The parametric factors were around 0.98 and 0.65. The regression plot is the accurate prediction of ODE solving and hence is cent percent accurate. All the solutions (indicated by crosses) lies exactly on the fixed-line (indicated by a red line). However, the one – way ANOVA tells the total accuracy of the whole model and the error acquired is around 3.16e+10 which are equal to 7 percentages. Hence the model achieves the required accuracy expectations and will be validated for future scopes.

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