Design Document - Knee Pain Classification System

General Description

Knee pain is one of the most common orthopedic problems worldwide, affecting the quality of life of millions—from young athletes to the elderly. The challenge in accurately diagnosing the severity of pain arises due to significant subjectivity: patients describe pain differently, and doctors rely on a combination of physical examinations, MRI/X-ray imaging, and patient reports. While existing imaging methods are accurate, they are expensive, time-consuming, and often unavailable in remote areas or for patients with mobility limitations. This is where our technology comes into play. The project focuses on analyzing thermal images using artificial intelligence, offering the potential for objective, fast, and accessible pain assessment without the need for expensive equipment or invasive tests.

Technological innovation

The project proposes a unique hybrid approach combining computer vision (CNN) with manually extracted statistical features. While most existing models rely solely on deep neural networks, integrating metrics such as entropy and pixel variance enables capturing complex patterns in thermal images—both at the micro level (e.g., localized inflammation areas) and the macro level (e.g., general heat distribution in the knee). Additionally, the system is designed to be adapted for clinical use:

- A simple user interface for medical teams, allowing image uploads and receiving results within seconds.
- A local database (SQLite) to maintain patient privacy and enable historical tracking.
- Bias detection mechanisms to identify and reduce demographic biases (e.g., age, gender).

Effectively, our system diagnoses pain levels based on knee scan images. For each patient, images of their scans can be uploaded, and the system evaluates the pain level based on the image.

Pain Classification Strategy:

- **Low Pain:** 1-33
- **Medium Pain:** 34-66
- **High Pain:** 67-100

General Software Structure

System Components

The system consists of the following components:

- **Desktop Application** – A graphical user interface (GUI) in Python for managing patients, uploading images, viewing pain analysis results, and handling the database.
- **Machine Learning Server** – Responsible for data processing, image analysis using a CNN neural network, and determining pain levels.
- **SQLite Database** – Used for storing patient information, scan images, and analysis results.

```
+------------------------------+
|     GUI (Desktop App)        |
|   - הרשמה והתחברות           |
|   - העלאת תמונות             |
|   - צפייה בתוצאות            |
+-------------+----------------+
              |
              v
+------------------------------+
|   ניהול מסד נתונים (SQLite)|
|   - טבלת מטופלים             |
|   - טבלת ניתוח תמונות        |
+-------------+----------------+
              |
              v
+---------------------------------+
|    עיבוד תמונה (Preprocessing)|
|   - שינוי גודל                  |
|   - הסרת רעשים                  |
|   - נירמול וטיוב תמונה          |
|   - חילוץ פיצ'רים               |
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              |
              v
+------------------------------+
|    רשת נוירונים (CNN)         |
|   - שכבות Convolution         |
|   - מיזוג עם פיצ'רים בסיסיים  |
|   - שכבה Fully Connected      |
|   - סיווג כאב (Softmax)       |
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```

Component Communication

The system will provide users with an interface. Upon logging in or registering, the patient will have access to their data. This screen will display the necessary information. By importing a file, the user can analyze and receive the pain level result for the image. The system will store the data in the database at appropriate tables. All calculations and processing occur locally within the application, without requiring network communication. The data is stored and retrieved from the local database.

User Interface

The system will include a basic Python-based user interface (using Tkinter) featuring:

- **Thermal Image Upload** – Ability to upload an image in PNG/TIFF format.
- **Result Display** – Showing the pain level as determined by the system (low, medium, high).
- **Patient Management** – Option to enter patient details, view test history, and delete old data.
- **Analysis Activation Button** – After uploading an image, the user can press a button to trigger the analysis and obtain results.

Patient login screen:

```
+----------------------------------+
|       Patient Registration       |
+----------------------------------+
| Name:  [____________]            |
| Age:   [__]                      |
| Gender: [Male/Female]            |
| Medical History: [___________]   |
|                                   |
| [Register] [View Patients]       |
+----------------------------------+
```

Internal screen for photo examination for a patient:

```
+--------------------------------+
|         Pain Analysis          |
+--------------------------------+
| Select Patient: [Dropdown List]  |
|                                |
| [Upload Thermal Image] [Button]  |
|                                |
| [Run Analysis] [Button]        |
|                                |
| [Results Display]              |
+--------------------------------+
```

Database and Data Storage

The system imports data into an SQLite-based database.

Database Table Structure:

Patients Table:

Description	Type	Column Name
Unique Patient ID	Integer	patient_id
Patient Name	Text	name
Patient Age	Integer	age
Patient Gender	Bool	gender
Medical History	Text	medical_history

Image Analysis Table:

Description	Type	Column Name
Image ID	Integer	image_id
Patient ID	Integer	patient_id
File Path	Text	image_path
Timestamp	DateTime	timestamp
Analysis Status	Text	analysis_status
Conclusion	Integer	result_id

Data Format:

- **Images:** Stored in PNG or TIFF format to maintain image quality.

Preprocessing Steps:

1. **Resizing Images to 128x128 pixels** – Ensuring uniform input size for the neural network.
2. **Noise Reduction** – Using Gaussian blur ($\sigma=1$) to minimize noise.
3. **Data Augmentation** – Random rotation (±15°) to increase data variety.

Model Structure

The model consists of two parts:

1. **Statistical Feature Analysis** – Identifying patterns using:
   - **Mean Value** – Average pixel values in the image.
   - **Entropy** – A measure of disorder in the image.
   - **Variance** – Distribution of values around the mean.
2. **Dual CNN Model** – Implemented with the following layers:
   - Conv2D
   - MaxPooling
   - Conv2D
   - MaxPooling
   - Flatten

By integrating these results, the final analysis is performed, and the image is classified accordingly.

Model Functions Used:

- **Activation Function:** ReLU
- **Output Layer:** Softmax with three categories (low, medium, high)
- **Loss Function:** Cross-entropy

Model Training Strategy:

- **Training Set:** 70% of the data
- **Validation Set:** 15% of the data (Cross Validation can be used to improve reliability)
- **Test Set:** 15% of the data

```
[Input Thermal Image (128x128x1)
                |
        ------------------
        |                |
   [CNN Branch]    [Basic Features]
        |                |
  [Conv2D 32]      Mean Value
        |          Variance
  [MaxPool]        Entropy
        |                |
  [Conv2D 64]            |
        |                |
  [MaxPool]              |
        |                |
  [Flatten]              |
        |                |
        ------------------
                |
      [Concatenate Layer]
                |
        [Dense Layer 64]
                |
      [Output Layer (3)]
                |
      [Pain Classification]
```

Backup Plan if Model Performance is Unsatisfactory

To improve results if the model does not perform well, we consider the following options:

Data-Level Improvements:

- Increasing augmentation (e.g., zoom, brightness adjustments)
- Collecting diverse thermal images, including additional statistical parameters like BMI

Model-Level Improvements:

- Hyperparameter tuning (e.g., learning rate, batch size)
- Adding Dropout layers (rate=0.5) to prevent overfitting
- Backup mechanism: Marking low-confidence results for manual review by a doctor

Bias and Fairness Analysis

We will examine potential biases such as gender and age.

Subgroup Analysis: Comparing accuracy/F1-score across:

- Gender (male/female)
- Age groups (<30, 30–60, >60)

Fairness Metrics Used:

- **Demographic Parity:** Ensuring equal pain classification rates across groups.
- **Bias Reduction:** Retraining with balanced data

Summary

The system consists of a desktop application integrating a local database and a neural network for processing thermal images. All image analysis is performed locally. The system is modular, allowing for improvements in accuracy through model refinements, data enhancement, and network architecture improvements.