Knee Contact Pressure Prediction

Project Sponsor:

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Mechanical and Biomedical Engineering

Project Repository:

https://github.com/cs481-ekh/f22-ai-cbl/

Release 1.0:

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1. Current Status

We accomplished three main tasks:

1.1. Data introduction

Created explanatory notebook knee_visualization.ipynb. This notebook allows people new in the biomedical field and who have yet to experience mesh data to get general information about seven knee structures and how that data is stored in mech object, see how data is visualized and interact with data.

Sponsor of the project provided three data sets:

- Set_1: Sep 13, 2022, 1 knee, 7 geometry structures, LE and S for 4 cartilages, 100-time points
- Set_2: Sep 29, 2022, 28 knees, 7 geometry structures, CPPRESS for tibia cartilages, 240-time points
- Set_3: Oct 19, 2022, 169 knees, 7 geometry structures, CPPRESS for tibia cartilages, 240-time points. Set_2 is subset of Set_3

Set_1 and Set_2 were used for features investigation and creating pipeline for data preparation for further analysis.
Set_3 was used for training and testing machine learning models.

1.2. Features extraction

Explored data and extracted simple features for each of 7 knee elements such as:

- size of the point cloud (number of points)
- volume
- bounds for x
- bounds for y
- bounds for z

and simulation length for the entire knee.

After the first round of training time series data, we saw that these simple features were not enough to get good prediction; therefore we extracted more complex features:

- femur gap distance

- label cartilage "healthy" or "damaged."
- mean, max, min distance between femur cartilages and tibia bone
- mean curvature of medial and medial tibia cartilages

Complex features for each knee of set_2 are visualized in complex_features_exploration.ipynb notebook. This notebook allows not only to introduce features but also checks the correctness of the feature extraction algorithm. For example, the yellow line for "femur gap distance" shows what distance is being measured.

patients_data_loading_set2.ipynb and patients_data_loading_set3.ipynb load data and extract features mentioned above.

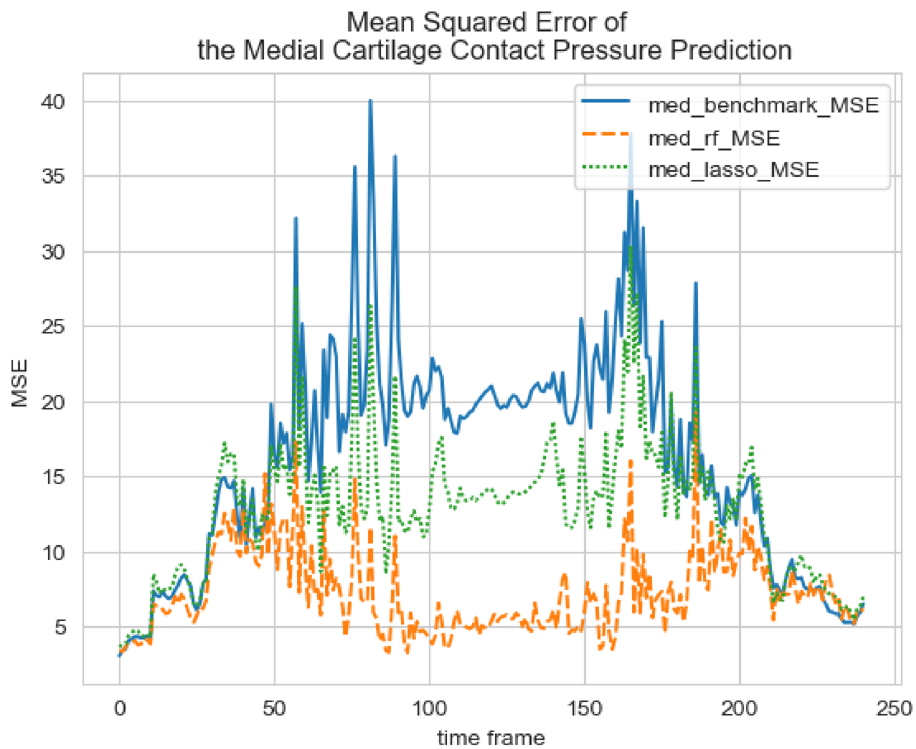
data_transformation_and_feature_eval_set2.ipynb and data_transformation_and_feature_eval_set3.ipynb go through the data cleaning process.

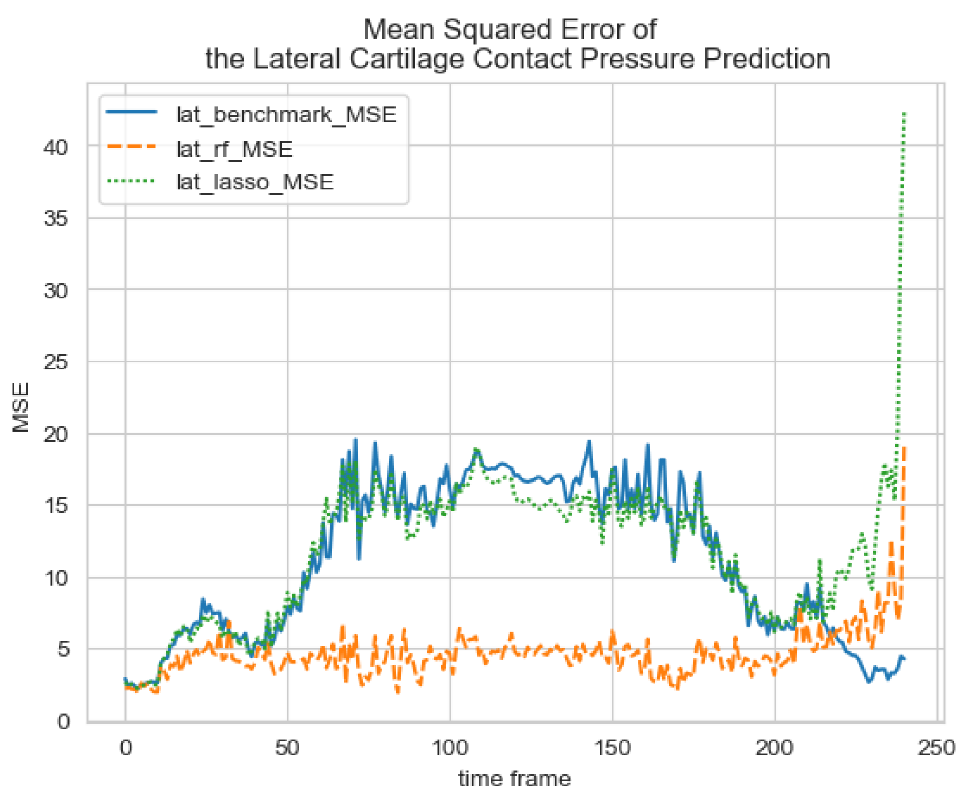
1.3. Training models and evaluating results

Set_3, the biggest data set, was divided into train and test, 80% and 20% correspondingly. Firstly, we tried to predict maximal peak stress for median and lateral cartilage. Five models were trained: Linear Regression, Regularized Linear Regression Lasso, Random Forest, XGBoost, and Multilayer perceptron. Mean square error (MSE) was quantified for each model on the test set. These metrics were compared with the Naïve benchmark, MSE when we used the mean of the training as a prediction for each event in the test set.

	Model	MSE for medial	MSE for lateral
0	Mean	53.933248	25.280210
1	Linear Regression	44.259566	28.091058
2	Lasso	39.331195	51.495012
3	Random Forest	36.028271	42.015581
4	XGBoost	40.315562	54.185539
5	MultiLayer Perception	7146.495407	2107.941451

For medial cartilage Lasso and Random Forest showed the best results; therefore, we used these models to predict time series peak contact pressure. The outcome MSE metrics comparison for medial and lateral cartilage is shown below.


Mean Squared Error of
the Medial Cartilage Contact Pressure Prediction
med_benchmark_MSE
med_rf_MSE
med_lasso_MSE
MSE
time frame
40
35
30
25
20
15
10
5
0
50
100
150
200
250


Mean Squared Error of
the Lateral Cartilage Contact Pressure Prediction
lat_benchmark_MSE
lat_rf_MSE
lat_lasso_MSE
MSE
time frame
40
35
30
25
20
15
10
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0
0
50
100
150
200
250

2. Thoughts

The results show potential for applying Random Forest and Regularized Linear regression models to predict the contact pressure of knee cartilages. However, more complex geometry features should be extracted, and additional data investigation should be done for lateral cartilage. Some ideas of new features are described in new-features-ideas.pdf document. Another feature that Dr.Fitzpatrick recommends extracting is cartilage thickness.

Increasing data size also benefits prediction accuracy; it would be worthwhile to introduce more data on patients with damaged knees.

After extracting new features and verifying the result on the set_3 data set or the new bigger data set, we recommend a switch to content a pressure map prediction, which assumes prediction pressure for each element of tibia cartilage. Element features should be extracted for that step. Some ideas for that features can include: the relative position of the element to the center (x,y,z), the relative position of the element to the edges (x,y,z), the thickness of the element.

3. Installation

3.1. Required Software

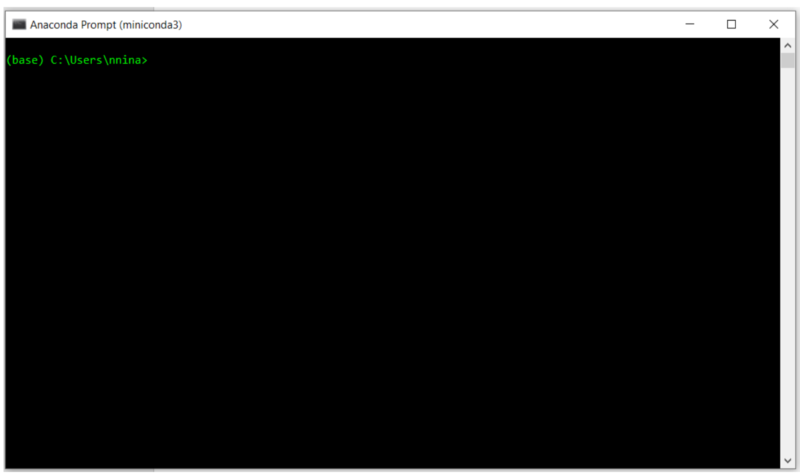
Install the following programs following the provided instructions, and preferably in the given order. Note that all given version numbers represent what was used at the time and is known to work – other versions may work but are not guaranteed

Miniconda

a. https://docs.conda.io/en/latest/miniconda.html
b. Version: > 4.10
c. Follow the Miniconda setup with default options – should be short, and nothing needs to be changed

3.2. Program Setup w/ Miniconda

1) Run the Miniconda application, which will open an Anaconda command window



Should open a window that looks like this, directed towards whatever your current user directory is

2) Load all files from the repository and navigate to the project folder.

3) Set up the conda environment from the ` environment.yml` file.

   conda env create -f sc_tutorial_environment.yml

4) Enter the environment by:
   $ conda activate fepredict
   or
   $conda activate ENV_NAME
   if you changed the environment name in the `environment.yml` file.

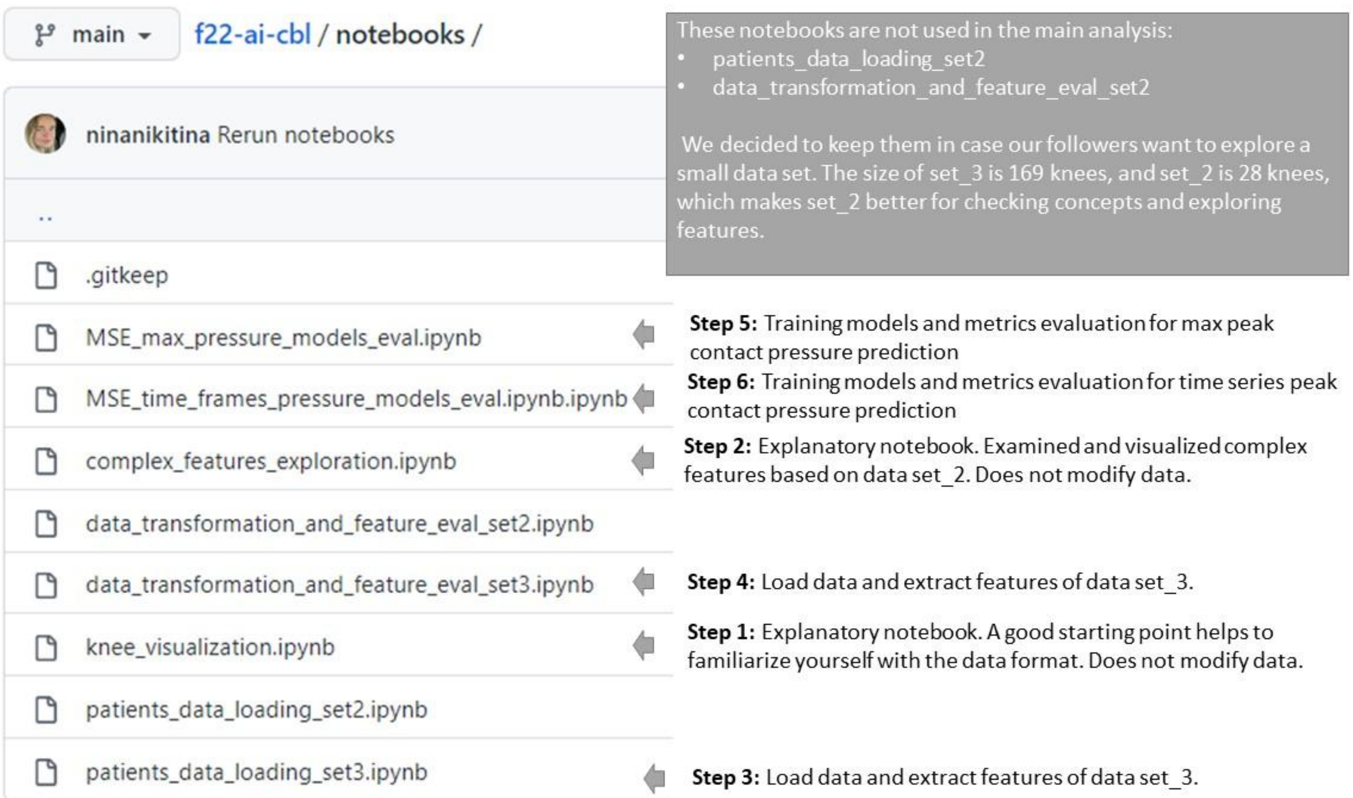
5) Navigate to the notebook directory and run Jupiter notebook

```
$ jupyter notebook
```

6) Choose notebook notebooks based on your needs. The description is provided in 3.3 Notebook overview.

If you prefer to set up an environment manually, a list of all package requirements are given at the end of this document.

3.3. Notebook overview



3.4. Manual installation of package requirements

The following packages are required to run the project notebooks.

General:

- Jupyter notebook
- Python >= 3.9

Python:

- Numpy
- Scipy
- Pandas
- Seaborn
- Matplotlib
- Pyvista
- OpenCV