HSS TEKSCAN ANALYSIS PROGRAMS (HSS-TAP)

User Manual

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Latest software version can be found at:
https://github.com/jiwooba/HSS-TAP

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Table of Contents

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Chapter 1

Preface and System requirements

1.1 Preface

This software was developed to overcome some of the limitations of the Tekscan I-Scan software. While this software is tailored towards the analysis of knee joint contact mechanics using the Tekscan 4010N and 4011 sensors, a majority of the analysis is generic enough to be used for other use cases and sensor types. The following chapters are broken down into types of analyses that can be performed using a step-by-step approach giving the general approach. Included with the code are example files that users can use to run through the code. These files have been validated by the authors to work with all aspects of the code. Each chapter is self-contained but will require users to be acquainted with only the materials covered in *Chapters 2 - 4* (GUI, converting Tekscan .fsx files and opening Tekscan .csv in the software).

The remainder of this chapter covers the requirements to use the Tekscan Analysis Program and the packaged files necessary to run the software.

1.2 System Requirements

1.2.1 Computer Requirements

PC & Macs that were purchased after 2008 will be able to run the basic functions. For the characteristic curve algorithm, a quad core processor is preferred but at minimum a dual core processor will be able to run the code. Processor-based graphics will be able to perform all necessary functions of the GUI.

1.2.2 MATLAB Requirements

This software has been tested on MATLAB versions 2014a to 2019b. Other versions may require further code adjustment.

The following MATLAB packages are required for the following analyses:
Image Processing Toolbox (required for drawing regions of interest)
Signal Processing Toolbox (required for smoothing of data)

1.2.3 Additional MATLAB Functions

Additional MATLAB functions were downloaded and included from the MathWorks File Exchange. Latest versions can be found at the links listed below:
Note: If software was downloaded from github these functions will need to be downloaded and included in the 'additionalFiles' directory.

cbrewer by Charles (Latest Version)
shadedErrorBar by Rob Campbell (Latest Version)
STAPLE by Andreas Husch (Latest Version)

Chapter 2

Graphical User Interface (GUI)

2.1 Background

The graphical user interface (GUI) has been designed to facilitate the user in interacting and analyzing Tekscan data files. This includes visualizing and reporting values for each individual sensel and statistics for the current frame. Analysis tools and comparisons between sensels and different test conditions have also been built into the GUI. This chapter will focus on the layout and components of the GUI with the use of the individual functions given in later chapters.

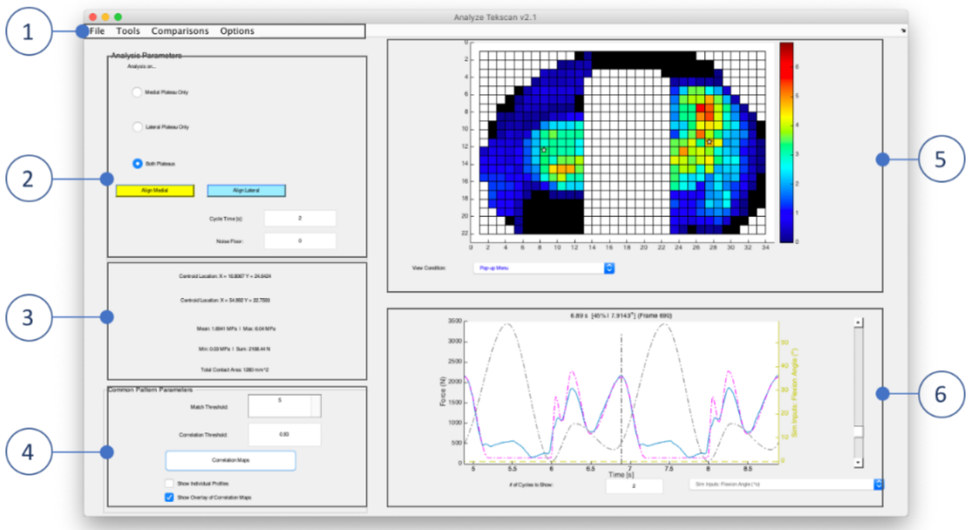


Figure 1: Tekscan Analysis Program Graphical User Interface (GUI)

2.2 The Graphical User Interface

The graphical user interface is broken up into 6 major sections that are shown in Figure 1 above.

1) *Menu Bar* – the menu bar contains 4 main categories:
    a. File – contains items for opening Tekscan data and saving data.
    b. Tools – contains tools that help with analysis of the Tekscan data.
    c. Calculate – calculations between sensels and test conditions.
    d. Options – contains items to tailor the display of Tekscan data in the GUI and outputs.
2) *Analysis Parameters* – area to set the length of a cycle and minimum sensel value to be considered in the analysis and the portion of the sensor to evaluate.
3) *Summary Statistics* – this section displays the statistical data for the portion of the sensor selected in the Analysis Parameters or ROI if one has been selected.
4) *Common Pattern Display* – this section contains components for the display of common patterns a description of which can be found in Section 8.3.
5) *Graphical Display of Tekscan Data* – this section shows a graphical representation of each sensel and its corresponding stress value as a heat map.
6) *Total Force Plot* – Displays the calculated total force vs time for the chosen analysis parameters. Additionally, this section allows users to navigate through the collected frames.

Chapter 3

Converting Tekscan .fsx files to .csv

3.1 Background

This chapter will guide the user in converting Tekscan files to the correct format for use in the GUI. This requires the use of the Tekscan I-Scan software to convert .fsx files to .csv files. The software has been validated for conversion of I-Scan versions 5.70I to 7.00-10I any versions after these may need modification to ensure the files can be properly opened.

Current manual provides instructions on converting .fsx files to .csv files using Tekscan I-Scan Version 7.00-10I.

3.2 Converting Files in Tekscan I-Scan

3.2.1 Opening Tekscan files

1) To open a Tekscan file (.fsx), click 'File' -> 'Open Movie...'.

3.2.2 Calibrating and Equilibrating .FSX files

1) Select 'Tools' -> 'Load Calibration File...'
2) Select a .cal file which is a generated calibration curve for that specific sensor.
3) Select 'Tools' -> 'Load Equilibration File...'
4) Select a .equ file which is data recorded from a uniform load applied.

3.2.3 Exporting Tekscan files as .CSV

1) Click 'File' -> 'Save ASCII...'. This will open a dialogue box (Figure 2).

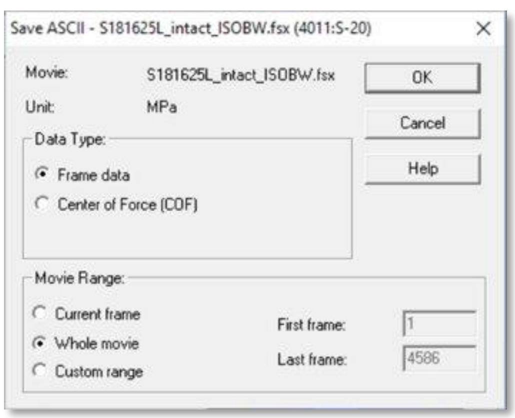


Figure 2: Dialogue Box to save .FSX file as a .CSV file

2) Select 'Frame Data' under Data Type.
3) Select 'Whole Movie' or 'Custom Range' under Movie Range. Click 'OK'.
4) Select a location where .CSV file will be saved.

Chapter 4

Opening files in Tekscan Analysis Program GUI

4.1 Background

This section will guide users in opening and adjusting the basic parameters in the main Tekscan Analysis Program GUI.

4.2 Opening .csv Files in GUI

4.2.1 Opening Files

1) To open a Tekscan exported csv, click ‘File’ -> ‘Open…’ or press Ctrl + O to open the menu dialogue. Figure 1 shows the GUI once you run the program in MATLAB.

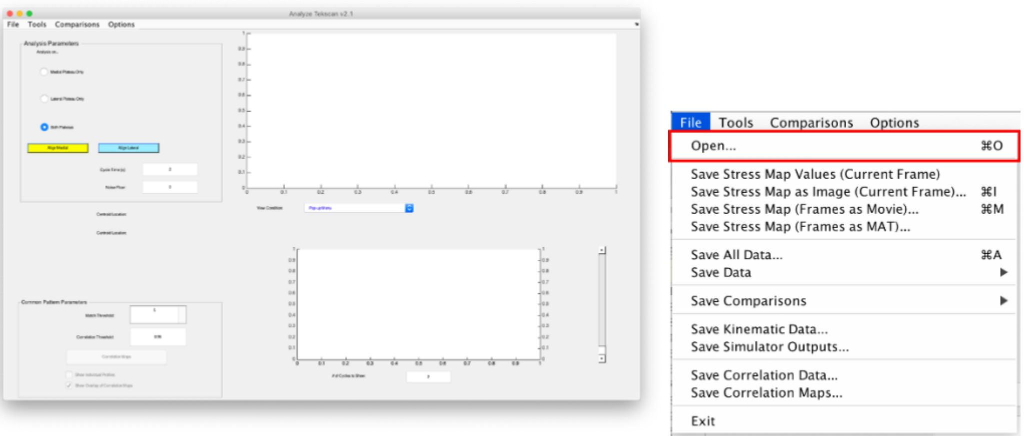


Figure 4: GUI after running in MATLAB and the File menu.

2) Select a Tekscan file and press ‘Open’.
3) A dialogue window will appear to allow users to give the option to label the condition (Figure 3). By default, the file name is populated in the text field. Once done press ‘Ok’.

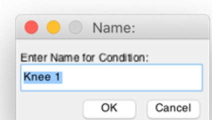


Figure 3: Dialogue box to name opened Tekscan file

4) Another dialogue box will appear prompting the user if this is a ‘Left’ or ‘Right’ knee (Figure). Selecting ‘left’ will mirror the sensels horizontally maintains orientation of the medial and lateral plateaus on the GUI.

5) The last dialogue window will open asking if there are more conditions that wanted to be loaded. By selecting ‘yes’, the process from steps 1-5 of the current section will be repeated until ‘no’ is selected at step 5.

Figure 4: Dialogue box to choose whether the specimen is a left or right knee

4.2.2 Adding New Files

1) If there are additional files that were not added using the steps in Section 4.2.1, they can be added to the analysis at any time by selecting ‘File’ -> ‘Open…’ or pressing Ctrl + O.
Note: Adding new files will remove all registration and analyses performed.
2) Repeat steps 1 – 5 from Section 4.2.1 for all additional files.

4.2.3 Registering with known pattern

If data is cyclic, users can register the data with a known pattern.

1) Click 'Tools' -> 'Registration' -> 'Register with known pattern…'
2) Select the .mat file that corresponds to the known pattern. Formatting for the pattern should be as follows:
    a. Force
    b. Flexion
    c. IE Torque

    Note: If no flexion or IE Torque is prescribed set all values to 0. Each variable should have the same length.

4.2.4 Show averaged data

If the data is cyclic, users can also register the data across multiple cycles.

1) Click 'Tools' -> 'Registration' -> 'Show Averaged Data…'
2) Select the cycles user would like to average

Note: Cycles counted backwards from the END.

Chapter 5

Creating and Manipulating Regions of Interest (ROI)

5.1 Background

In many applications of Tekscan sensors, a particular subset of sensels are of interest. In previous work of the Maher lab, ROIs have been used to delineate between areas of cartilage-cartilage contact and cartilage-meniscus contact.

In an effort to reduce intra- and inter-observer variability, a semi-automatic method of selecting an ROI was developed. For this method, a user manually selects an ROI where it is easy to distinguish between cartilage-cartilage and cartilage-meniscus regions. Activecontour, a built-in MATLAB function, segments the frame into foreground and background by finding object boundaries. A Gaussian curve is than applied where the peak is set to the location of the peak within the foreground, found from the activecontour function. This is now the ROI. For the next frame, the previous ROI is used and the activecontour and Gaussian smoothing process is repeated through an entire gait cycle. This was an experimental code that proved to not decrease variability or reduce time spent selecting ROIs throughout a dataset.

For guidance on how to properly select a ROI or how to train new users, reference Chapter 9: Training New Users.

5.2 Creating a New ROI

5.2.1 Manually Drawn

1) Select 'Tools' -> 'Region of Interest' -> 'New ROI'.
2) Use the mouse to designate an enclosed ROI so that the first and last point of the polygon are the same.
3) Double click within the ROI. This will turn the perimeter red.

5.2.2 Semi-Automated (Experimental)

1) Find a frame where it is easy to delineate the ROI from its background.
2) Select 'Tools' -> 'Region of Interest' -> 'New Semi-Auto ROI'.
3) Use the mouse to designate an enclosed ROI so that the first and last point of the polygon are the same.
4) Double click within the ROI. This will turn the perimeter red and calculate the ROI throughout an entire dataset. This can take a few minutes.

5.2.3 Creating a Consensus ROI using the STAPLE method

1) Select 'Tools' -> 'Region of Interest' -> 'New STAPLE ROI...'.
2) Select multiple .roi files, and then select 'Open'. These .roi files should all be located in the same folder.
3) This will take a few minutes. Once complete, a consensus ROI outlined in red from the inputted ROIs selected by the user.

5.3 Manipulating ROIs

5.3.1 Copying ROIs

1) Select 'Tools' -> 'Region of Interest' -> 'Copy ROI' -> 'Reverse' or press Ctrl + R to copy a region of interest back one frame.

2) Select 'Tools' -> 'Region of Interest' -> 'Copy ROI' -> 'Forward' or press Ctrl + F to copy a region of interest forward one frame.
3) Select 'Tools' -> 'Region of Interest' -> 'Copy ROI' -> 'Replace All' to copy a region of interest throughout an entire dataset.

5.3.2 Editing ROIs

1) Select 'Tools' -> 'Region of Interest' -> 'Edit ROI'.
2) Shift entire ROI shape by clicking inside the ROI and dragging to desired location.
3) Alter vertices of the ROI by clicking on the point and dragging to desired location.
4) Delete vertices by right clicking on vertex and selecting 'Delete Vertex'.
5) Alter color of the ROI by right clicking within the ROI and selecting 'Set Color'

5.3.3 Removing ROIs

1) Select 'Tools' -> 'Region of Interest' -> 'Remove ROI' to remove all ROIs from a dataset.

5.4 Loading and Saving ROIs

5.4.1 Loading ROIs

1) Select 'Tools' -> 'Region of Interest' -> 'Load ROI...'.
2) Select a previously saved ROI.

5.4.2 Save ROIs

1) Select 'Tools' -> 'Region of Interest' -> 'Save ROI...'.

5.4.3 Save ROI Statistics

1) To save ROI area throughout a dataset in a .csv file, select 'File' -> 'Save Data' -> 'Save Contact Area...' or select 'File' -> 'Save All Data...' and the file will be saved in the format "path\filename_ROI_CA" and "path\filename_ROI_CA_avg". The avg file outputs the result of the last 5 cycles averaged or the range set by user in 'Tools' -> 'Show Averaged Data'.

5.5 Displaying ROIs

5.5.1 ROI Graphical Display Options

1) Select 'Options' -> 'Round ROI Points' to turn on/off rounding all ROI vertices to the nearest sensel corner.
2) Select 'Options' -> 'Show ROI Points' to show/hide the red perimeter of the ROI.
3) Select 'Options' -> 'Highlight ROI Area' to show/hide a yellow overlay which indicates a sensel is include in a ROI.

Chapter 6

Visualizing and Exporting Map Data

6.1 Background

WCoC is calculated by taking a weighted average within a drawn ROI. It appears as a white star on the graphical display of Tekscan data. The WCoC output provides a more reliable and accurate depiction of load distribution across the sensor compared to maximum contact pressure: a metric used frequently in the literature [cite articles].

6.2 Saving Contact Pressure Statistics

All WCoC and maximum and mean contact pressure statistics can be plotted by selecting ‘Tools’ -> ‘Plotting’.

6.2.1 WCoC

1) To save WCoC location and velocity and slope, intercept, and rotation between WCoC of the medial and lateral compartments throughout a dataset as a .csv file, select ‘File’ -> ‘Save Data’ -> ‘Save Center of Stress Data...’ or select ‘File’ -> ‘Save All Data...’ and the file will be saved in the format “path\filename_ROI_WCoC” and “path\filename_ROI_WCoC_avg”.
2) ‘File’ -> ‘Save Data’ -> ‘Save Center of Contact Data...’
3) To visualize WCoC path throughout a data set, select ‘File’ -> ‘Save Stress Map as Image (Current Frame)...’ or select ‘Ctrl + I’. This will output Figure 1Figure 5: WCoC path throughout a data set. For gait data, the WCoC path will be split into a stance and swing phase.. For gait data, WCoC will be split into two phases: stance and swing.

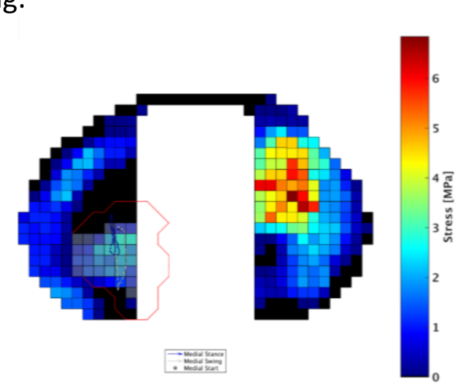


Figure 5: WCoC path throughout a data set. For gait data, the WCoC path will be split into a stance and swing phase.

6.2.2 Contact Area

1) To save contact area throughout a dataset as a .csv file, select ‘File’ -> ‘Save Data’ -> ‘Save Contact Area...’ or select ‘File’ -> ‘Save All Data...’ and the file will be saved in the format “path\filename_ROI_CA” and “path\filename_ROI_CA_avg”.

6.2.3 Minimum, Maximum, and Mean Contact Pressures

1) To save minimum, maximum, and mean contact pressures and locations and sum of forces within an ROI throughout a dataset as a .csv file, select ‘File’ -> ‘Save Data’ -> ‘Save Statistics for Current Map...’

or select ‘File’ -> ‘Save All Data...’ and the file will be saved in the format “path\filename_ROI_stats” and “path\filename_ROI_stats_avg”.

Chapter 7

Visualizing Raw Tekscan Data

7.1 Background

This chapter is based on the I-Scan software's method of visualizing raw Tekscan data through quadrant and secant maps. Other ways to save raw data are included in this chapter.

7.2 Displaying Data

7.2.1 Quadrant and Secant Maps

1) A quadrant map breaks down Tekscan data into 8 regions with mean and maximum contact pressure values for each region. To output a quadrant map select 'Tools' -> 'Quadrant Stresses' or 'Ctrl + P'. If an ROI is drawn, the ROI will be split into 8 regions.
2) To save quadrant or secant maps, select 'File' -> 'Save Data' -> 'Save Quadrant Data...' or 'Save Secant Data...'

7.2.2 Saving Raw Data

1) To save current frame as a .mat file, select 'File' -> 'Save Stress Map Values (Current Frame)'
2) Save an entire dataset as a movie by selecting 'File' -> 'Save Stress Map (Frames as Movie)…'
3) Save an entire dataset as a .mat file by selecting 'File' -> 'Save Stress Map (Frames as MAT)…'

Chapter 8

Comparing Within and Between Datasets

8.1 Background

When comparing two test conditions, Tekscan data can be visualized through difference maps. Within a data set, common patterns can be found through a normalized cross-correlation analysis.

8.2 Difference Maps

8.2.1 Creating and Saving Difference Maps

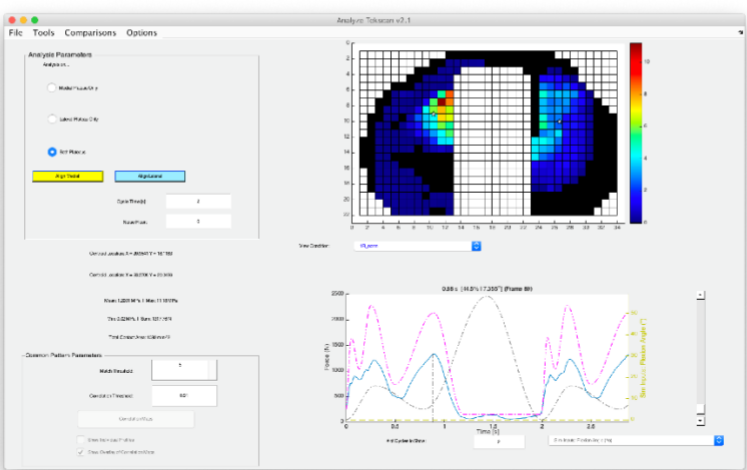
1) After opening two Tekscan files, difference maps can be created by selecting ‘Comparisons’ -> ‘Magnitude Difference (Red-Blue)…’ and then checking the ‘Show Difference Maps’ box.
2) Difference maps can be saved by going to ‘File’ -> ‘Save Comparisons’

8.2.2 Types of Difference Maps

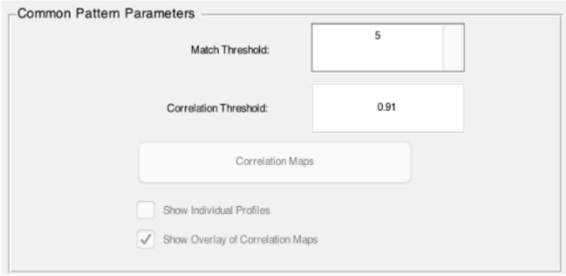
1) Load Magnitude directly subtracts one data set from another throughout an entire gait cycle.
2) Max Load Magnitude finds the difference at the frame that experiences the highest force.
3) Min Load Magnitude find the difference at the frame that experiences the lowest force.
4) Max/Min Load Magnitude is a combination of Max Load Magnitude and Min Load Magnitude.
5) Load pattern is the difference in the pattern at each sensing element between two test conditions can be performed. This method calculates 1-NCC (Normalized Cross Correlation) giving a maximum difference between the patterns at each sensing element location.
6) Combined is the multiplication of the pattern difference at each sensel with the max/min stress at each sense.

8.3 Common Patterns

1) Open all test conditions into the Tekscan GUI and pick “known pattern” file (as described in Chapter 4)

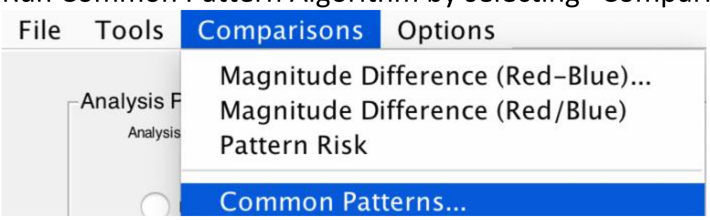


2) Change “Common Pattern Parameters” to designed values.

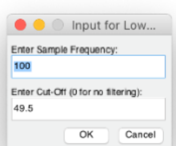


   a. Match Threshold: The minimum number of sensels that need to have the pattern to be considered a match.
   b. Correlation Threshold: The minimum normalized cross-correlation value to be considered a match. Values range from 0 to 1 with 0 being completely dissimilar and 1 a perfect match.

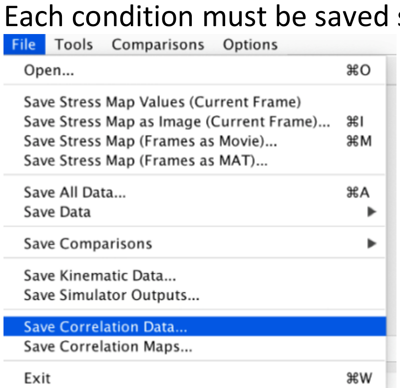
3) Run Common Pattern Algorithm by selecting “Comparisons” -> “Common Patterns…”



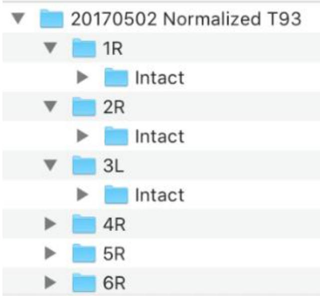
4) Select desired low pass filtering. The code uses a butterworth filter. Entering 0 as the cut-off disables filtering. *In most cases setting the ‘Cut-Off’ to 0 provides the best results.*



5) Each condition must be saved separately by going to “File” -> “Save Correlation Data…”



Save files in the following format: “Base Folder” -> “Specimen” -> “Condition”



6) After saving all conditions. Repeat steps 1 through 5 for all remaining Specimens
7) In MATLAB open “charcurvefinder_v2.m” and set the following parameters:
    a. Window_size -> this variable is the length of data points that make up one cycle. This can be calculated based on the sampling rate used to acquire the tekscan data and the cycle frequency in seconds/cycle.
    b. Num_cycles -> number of cycles saved through the program. This value should be 1 by default.
    c. Threshold_value -> this variable determines the normalized cross-correlation threshold value to use for the comparisons
    d. Location2 -> this is the base folder location of the specimen files
    e. Fold2 -> this is the condition that you want to compare between knees
    f. kneeID -> this is the label for the folders for each knee

```
repeats = 1;
window_size = 200; %number of points that constitute one cycle of data
num_cycles = 1; %number of cycles saved
threshold_value = 0.93; %threshold value
counter = 1;
tracker = 0;
rel_abs = 1;

corr_patterns(1).patterns = {};
corr_patterns(1).ncc_value = [];
corr_patterns(1).shift = [];
corr_patterns(1).knee = [];
corr_patterns(1).sample = [];

%%--------location of individual pattern files----------
location2 = '/Users/txc/OneDrive/HSS DATA/Cadaveric Studies/Intact Knees/20170502 Normalized T93/';
fold2 = '/Intact';
kneeID = {'1R','2R','3L'...
    '4R'...
    ...
    };
```

8) Run the program. This will automatically generate output files for the specified condition in the location set in the “location2” variable.
9) In MATLAB open “char_curve_output_sep.m” and set the following parameters:
    a. Path -> location where the output file in step 4 is locationed.
    b. File -> the name of the output file to open
    c. Window_size -> this variable is the length of one cycle. This can be calculated based on the sampling rate used to acquire the tekscan data and the cycle frequency in seconds/cycle. * window size should be the same as used in step 7.
    d. Min_crange -> the minimum value for matches to show. Any match below this value will show up as black on the heat map
    e. Max_crange -> the maximum value for matches to show. Any match above this value will show up as red.
    f. Cut_off -> the minimum number of knee matches that will be considered a common pattern
10) Run the program. This will automatically generate and output the figures based on the parameters set. The following files are generated:

a. …_KneeMap.Tiff -> Heat map with number of knees show
b. …_norm_corr_map.txt -> raw data for all matches. Each column is a separate match curve
c. …_NormCurve.tiff -> Graph with normalized matched curves overlayed.
d. …_weight_CI.txt -> Common pattern weighted per sensel by the number of knees with the same pattern at that sensel. Mean ± 95% confidence interval
e. …_weight_STD.txt -> Common pattern weighted per sensel by the number of knees with the same pattern at that sensel. Mean ± standard deviation
f. …_weighted_max_map.txt -> max stress at each common sensel
g. ..._WeightedCI.tiff -> Common pattern weighted per sensel by the number of knees with the same pattern at that sensel. Plotted as Mean ± 95% confidence interval
h. …_WeightedSTD.tiff -> Common pattern weighted per sensel by the number of knees with the same pattern at that sensel. Plotted as Mean ± standard deviation.

Chapter 9

Training New Users

9.1 Background

New users can be trained to properly segment out ROIs through a sensitivity and specificity analysis that compares new users' ROIs to experts' ROIs outputted from the STAPLE code. To show differences between expert ROI and user ROIs an overlay function was created.

9.2 Reading Tekscan Data

Tekscan data is in the form of a heat map with red corresponding to higher pressure readouts and blue corresponding to lower pressure readouts. Each square corresponds to a sensel (2mm x 2mm) from the Tekscan sensor. The star denotes the weighted center of contact for both sides of the sensor. Figure 6 shows the correlation between the orientation of the Tekscan sensor and the orientation of the Tekscan data outputted in the MATLAB GUI.

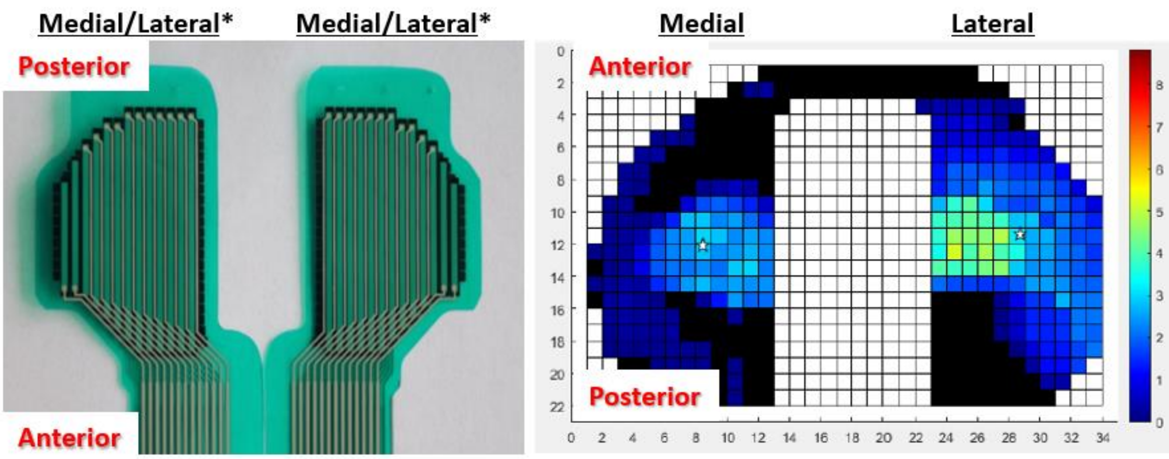


Figure 6: Tekscan sensor (left) and outputted Tekscan data (right). The directionality of the Tekscan sensor depends on whether the sensor is inserted into a left or right knee.

9.3 Designating a ROI

9.3.1 Cartilage-Cartilage ROI

For the Maher lab, the region of interest is the cartilage-cartilage region. The cartilage-cartilage area is a circular shape inside the cartilage-meniscus region (a c-shaped region around the perimeter around the medial and lateral sides of the sensor). The ROI is drawn by outlining the sensels that are higher in magnitude in the center of the medial compartment. See Figure 7 for examples.

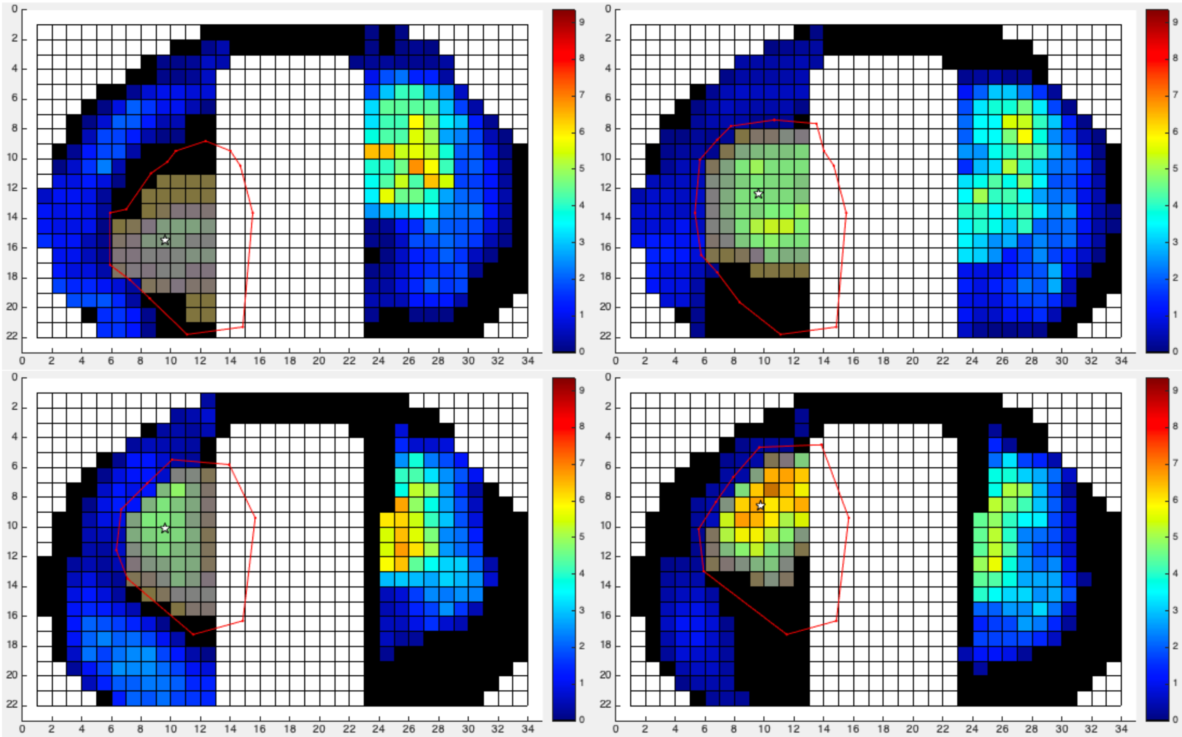


Figure 7: Cartilage-Cartilage ROIs

How the program works:

1) The sensel is included in the ROI if the upper left corner of the sensel is inside the drawn ROI
2) Black sensels will not be included when calculating statistics such as contact area.

9.3.2 Editing ROIs

See 5.5 Displaying ROIs for options on how to visualize ROIs. Rounding and highlighting help the user to refine the ROI shape.

9.4 New Trainee Assessment

9.4.1 Sensitivity and Specificity Analysis

In scenarios where the true ROI is not known, a STAPLE algorithm (5.2.3) can be used. In this expectation-maximization algorithm, multiple experts' ROIs are inputted and the true ROI is calculated by maximizing specificity and sensitivity. New trainees can be assessed based on a sensitivity and specificity analysis calculated to the expert outputted true ROI. For our study, an inclusion criterion for observers was 80% sensitivity and 98% specificity.

9.4.2 Compare to Expert ROI

The True or STAPLE generated expert ROIs can be used to train new users with identifying regions of interest through all frames. This can be performed against all frames or averaged cycles (4.2.4). To perform this training:

1) Load tekscan file used for training using steps listed in 4.2.
2) Start comparison module by clicking 'Tools' -> 'Region of Interest' -> 'Compare to Expert ROI…'
3) Load expert ROI file when prompted

4) Load trainee ROI files when prompted. A single ROI or multiple ROIs may be selected. These files should be kept in the same folder if loading multiple.
5) If multiple trainee ROIs were loaded use dropdown menu (shown in Figure 8 – 1) to select the ROI to view.
6) Sensitivity and specificity for the selected trainee ROI is shown in Figure 8 – 2.
7) The program will then show the ROI outlines and highlights if user selected those options (see 5.5.1). Expert ROI is shown in red and the trainee ROIs are shown in green. (Figure 8 – 3).
8) Sensitivity and specificity values for all frames can be exported by clicking 'Tools' -> 'Region of Interest' -> 'Save Sensitivity/Specificity'. This will save data for only the current selected trainee ROI.

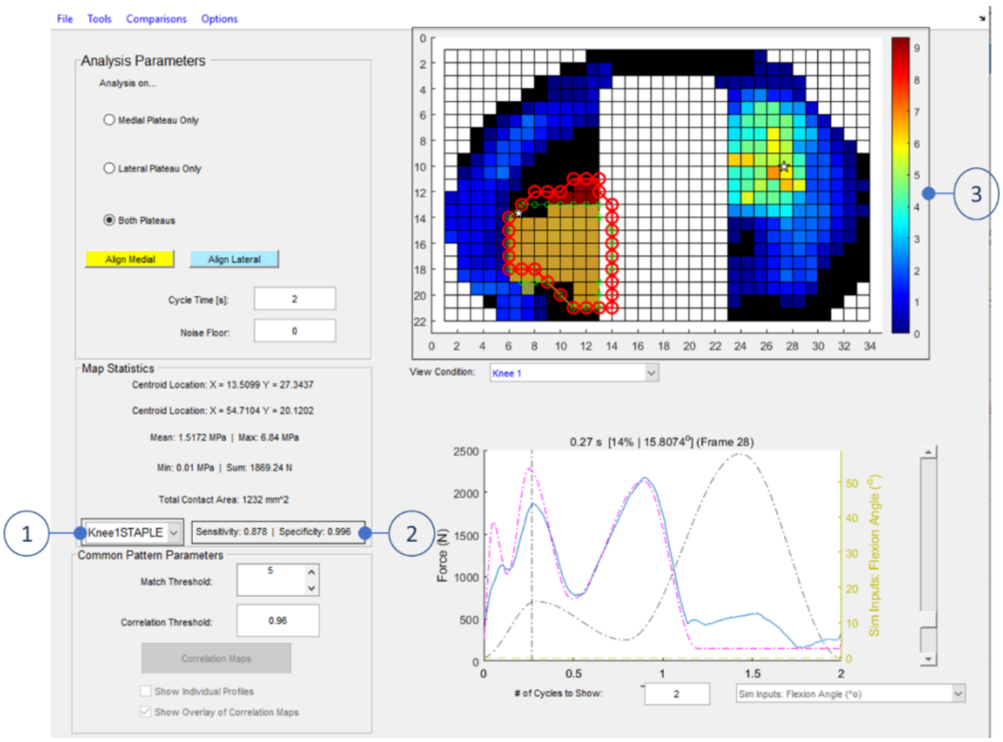


Figure 8: GUI with comparisons to Expert ROI