



Foot System to Evaluate Pressure and Shear (FootSTEPS)

Operation Manual (version 6)



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Innovative Scientific Solutions, Inc.

For questions or comments, please contact ISSI

Innovative Scientific Solutions, Incorporated

7610 McEwen Road

Dayton, OH 45459

Ph.: (937) 630-3012

Fax: (937) 630-3015

www.innssi.com/FootSTEPS

Email: issi-sales@innssi.com

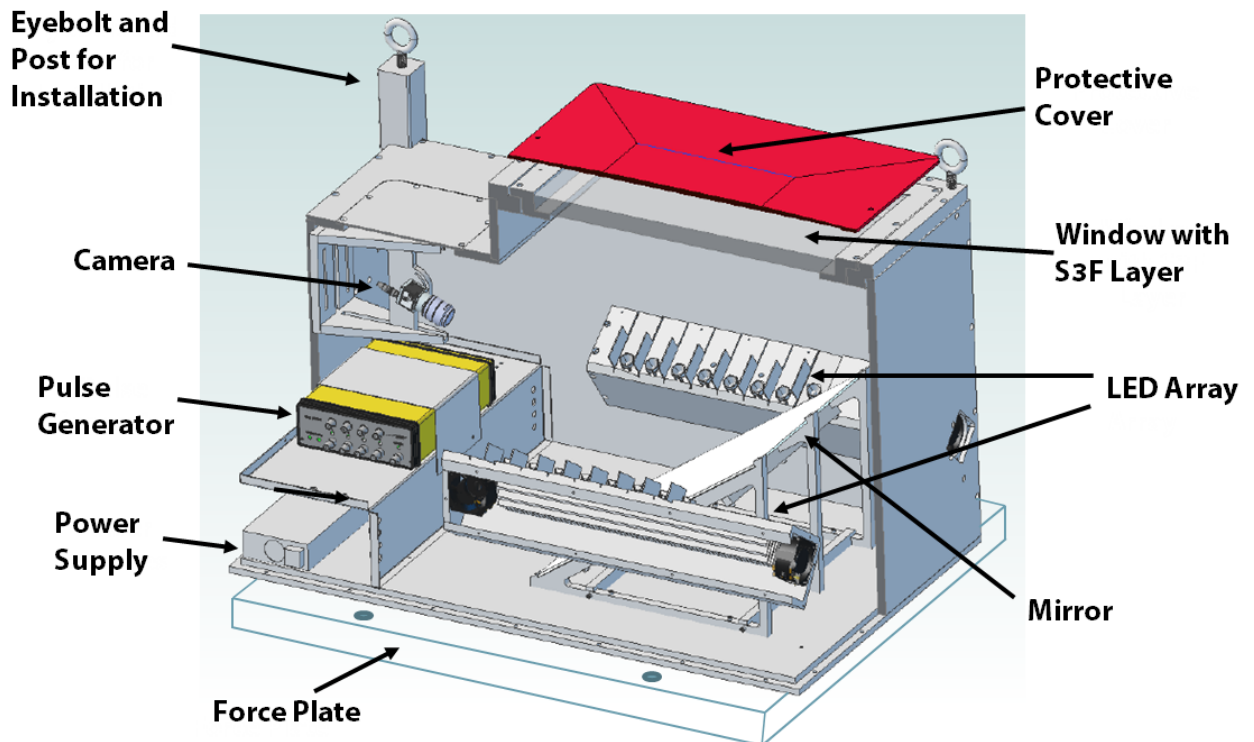
Introduction

ISSI's FootSTEPS technology provides the first-ever capability to measure normal and shear force distributions under the entire foot during gait testing. The information is captured dynamically with the frequency determined by the camera data capture rate.

The FootSTEPS system integrates ISSI's patented Surface Stress Sensitive Film (S3F) technology with a force plate system produced by companies such as Bertec, AMTI, and Kistler.

The resultant FootSTEPS system provides the "best of both worlds" ... distributed normal and shear force measurements, not available in any other system, combined with ground reaction force measurements that gait researchers know and trust.

System Drawing



CAUTION: As shown in the system drawing there are removable ports and panels on the system optical box. Removal of any of these items can result in a loss of optical alignment and calibration of the system. Port or optical window removal should only be done under instruction from ISSI.

Principle of Operation

A single high-resolution camera images an S3F layer polymerized on a 1-inch thick tempered glass window located in the upper surface of the FootSteps system box. The mirror arrangement allows for a longer optical path and the use of lenses with low optical distortion. LED arrays, located below and to either side of the window, illuminate the film for camera operation. The optical box also contains power supplies for camera and LEDs, as well as a pulse generator that synchronizes LED pulses and camera framing. Cooling fans ensure a stable operational temperature.

The force plate, mounted underneath the optical box, simultaneously measures three forces and three moments about the x, y, and z axes. Synchronized data collection is initiated by a trigger pulse from the force plate on initial foot contact. The data collection period ends when no contact is detected, or when the maximum number of camera images is collected. This maximum is sufficient to ensure full data capture regardless of the direction of travel across the FootSTEPS system.

The non-compressible S3F layer contains a probe that enables changes in film thickness, produced primarily by normal foot contact forces, to be visualized as changes in illumination level. The mathematical ratio of loaded and unloaded images quantifies the vertical displacement of the film. A series of markers are applied to the film below the opaque upper layer. These markers are displaced laterally during foot contact, primarily by tangential forces. Cross-correlation analysis quantifies the displacements produced by shear forces. 3-D displacement maps provide rapid visualization of the pressure and shear patterns produced by plantar contact. Reconstruction of the pressure and shear force values is provided by offline analysis using a finite element model of the S3F with the measured displacements as inputs.

Description & Specifications

Power	110-120 VAC
Interface	Dedicated USB 3.0 for camera connection (HighPoint Rocket U 1144C is recommended. Call ISSI for guidance if you cannot obtain this specific card). USB 2.0 for others.
Linear Pressure Range	15 to 700 kPa. Unsaturated response to greater than 2000 kPa.
Linear Shear Range	3 to ± 100 kPa. Not saturation point; limit without test form slippage.
Accuracy	$\pm 5\%$ of full scale for both pressure and shear.
Crosstalk	Less than 3% between pressure and shear.
Data Capture Rate	50 frames per second.
Spatial Resolution for Reconstructed Forces	2 mm.
Active Measurement Area	32 by 43 cm (12.6 by 17 inches).
S3F and Force Plate Data Streams	Synchronized via force plate amplifier signal.
Software	<ul style="list-style-type: none"> • Acquires images and force plate data. • Computes normal and tangential film displacements. • Provides immediate post-run display of the pressure and shear displacements to insure that good data were collected. • Reconstructs the pressure and shear forces using freeFEM++ and offline batch processing. • Displays pressure and shear maps, plots pressure and shear values temporally and spatially, and conducts mask-based analysis.
Weight	305 lbs, not including the force plate.
Size	91.4 cm (L) by 53.3 cm (W) by 54.9 (H). (36 by 21 by 21.625 inches), not including the force plate.
Warranty	24 months – see License Agreement and Limited Warranty. 6 months – S3F layer, excluding damage caused by customer mishandling.
Product Maintenance	24 months – see License Agreement and Limited Warranty.

Software Installation

1. Instructions for Loading the FootSTEPS Data Acquisition Software

The FootSTEPS acquisition software is 64-bit and compiled for 64-bit Windows operating systems Vista, 7 and 8.1.

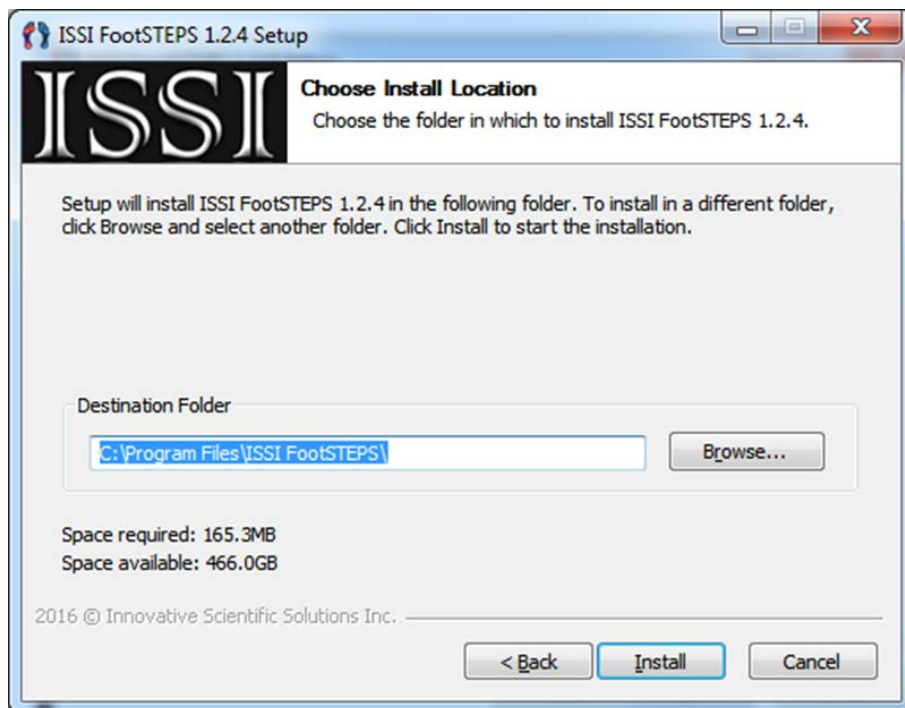
Run **Setup_FootSTEPS_acquisition_interface.exe**. The setup page will open and prompt the user to continue with the installation.

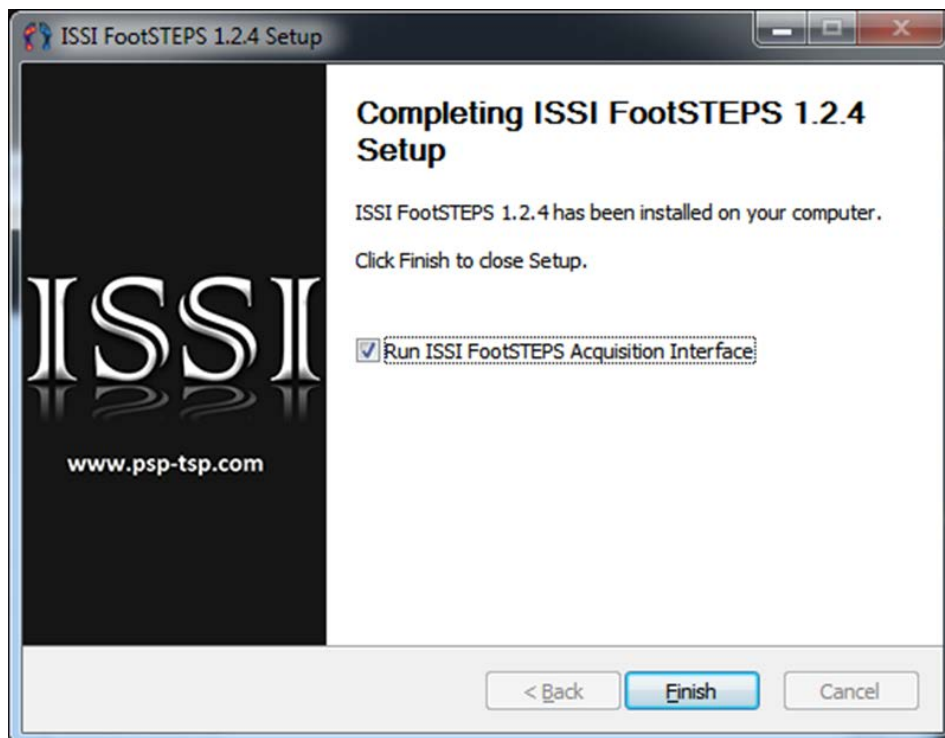
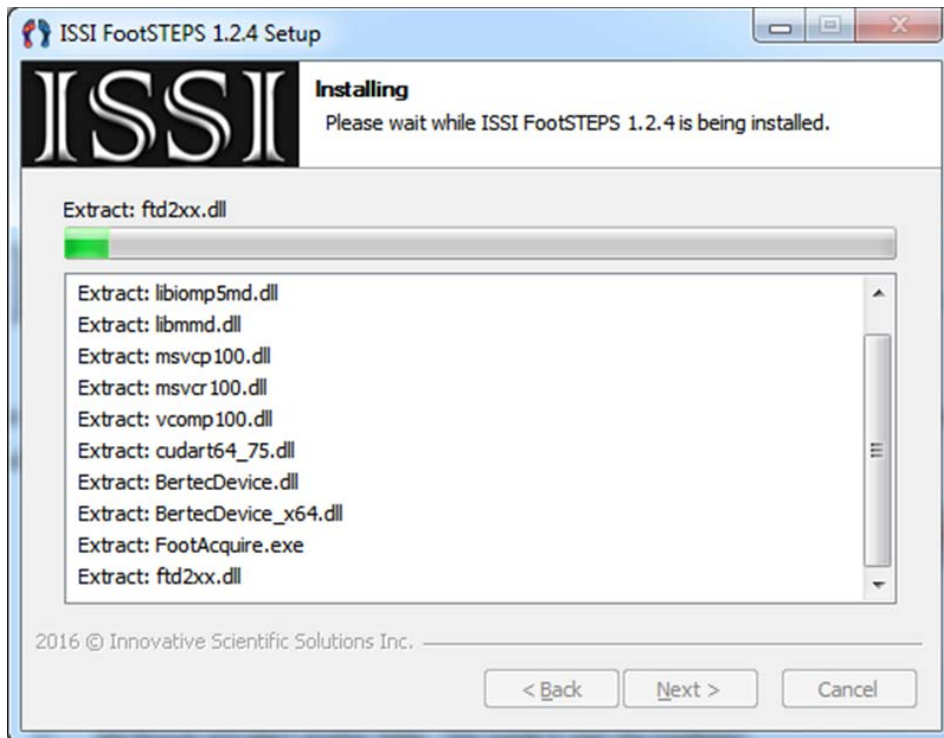


The setup will next open and display the license agreement for the software.



Confirm the destination where the software will be stored and proceed with the installation.



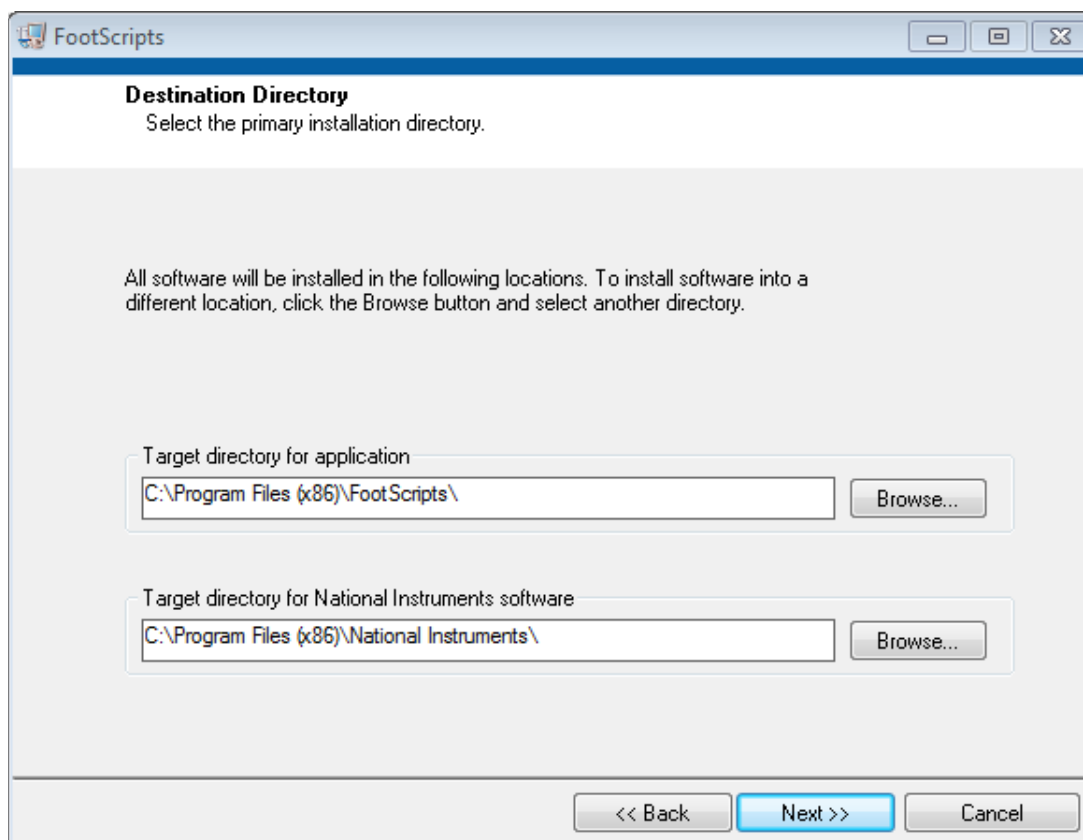


Ensure that all USB-devices (Camera, ISSI Pulse Generator (PSG), and Force Plate) have drivers by checking the **Windows Device Manager**.

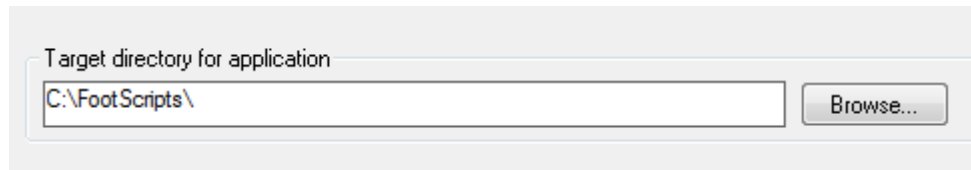
2. Instructions for Loading the FootSTEPS Data Analysis Software

The software for batch analysis of step data from the FootSTEPS system consists of four separate programs. These programs include: FreeFEM++, FootScripts, Foot_Analysis_Scheduler, and FootPlots. The FreeFEM++ program is freeware available for download from the internet, while the other programs are C-based programs available only from ISSI.

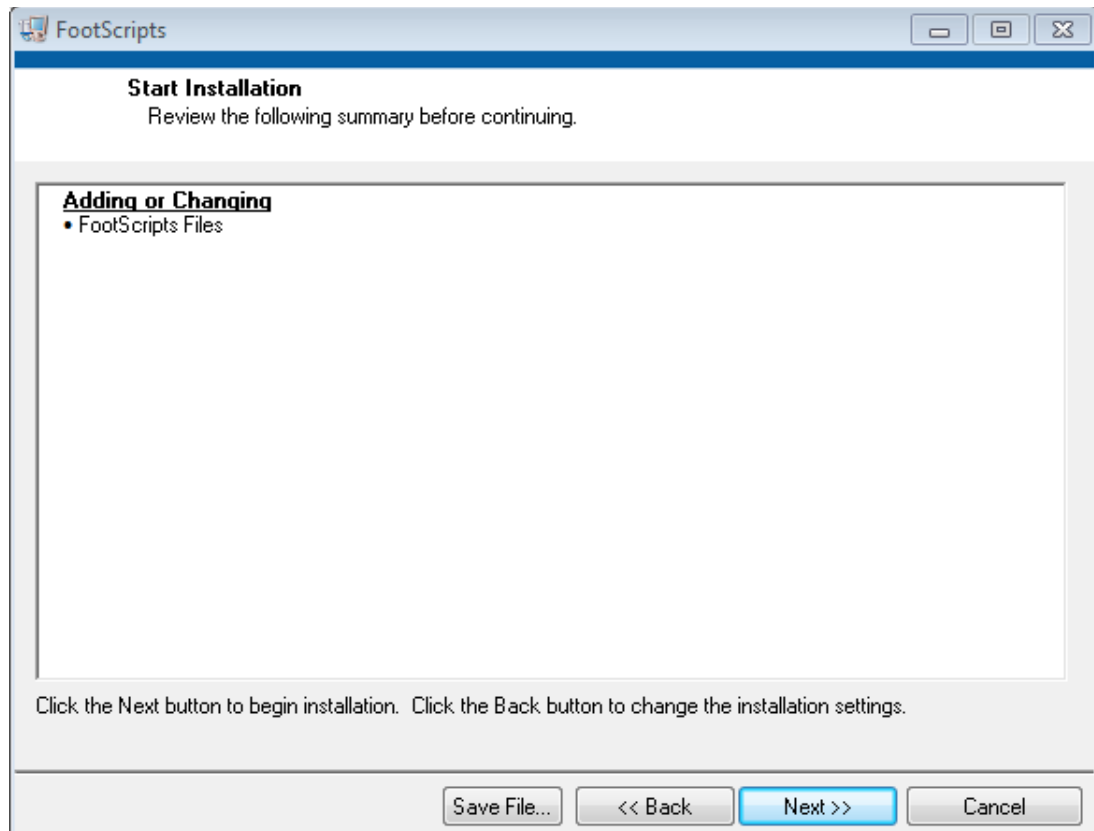
- a. Installing FreeFEM++ v3.46: Please navigate to the following site: <http://www.freefem.org/ff++/> and select from the download precompile version section the Windows 32bit: FreeFEM++-3.46-win32.exe package. Download and install this package.
- b. From the installation package supplied by ISSI go to the FootScripts folder and locate `cvidistkit.FootScripts_1`. Open this folder and the Volume folder located inside and find the setup program. Launch the setup program and the following Destination Directory dialog will appear:



Change the target directory from C:\Program Files (x86)\FootScripts\ to C:\FootScripts\



and hit the next button. The review dialog will appear asking you to confirm the installation, hit next to complete the installation.



The FootScripts program will now be located in the startup menu and directly in the c:\FootScripts\ folder. Once the setup is complete, copy all remaining files from the ISSI FootScripts folder into the c:\FootScripts\ folder. It is not necessary to overwrite the just installed files. The FootScripts program should now be fully installed and ready for use.

- c. From the installation package supplied by ISSI go to the FootPlots folder and locate cvdistkit.FootPlots. Open this folder and the Volume folder located inside and find/run the setup program. Follow the same steps as discussed in the

FootScripts installation, namely, change the target file to the c:\FootPlots\ folder, hit the next button to start the installation and when the installation is complete copy all folders from the ISSI supplied FootPlots folder to the newly installed c:\FootPlots\ folder.

- d. From the installation package supplied by ISSI go to the foot_analysis_scheduler folder and locate the cvidistkit.foot_analysis_scheduler_1. Open this folder and the Volume folder located inside and find/run the setup program. Follow the same steps as discussed in the FootScripts installation, namely, change the target file to the c:\foot_analysis_scheduler\ folder, hit the next button to start the installation and when the installation is complete copy all folders from the ISSI supplied foot_analysis_scheduler folder to the newly installed c:\foot_analysis_scheduler\ folder.

Hardware Installation

1. Connect the computer and FootSTEPS system box with two USB cables:

Connect the one with the blue connector and blue insert to the dedicated USB 3.0 port on the computer and the other to a USB 2.0 port (black or white insert).

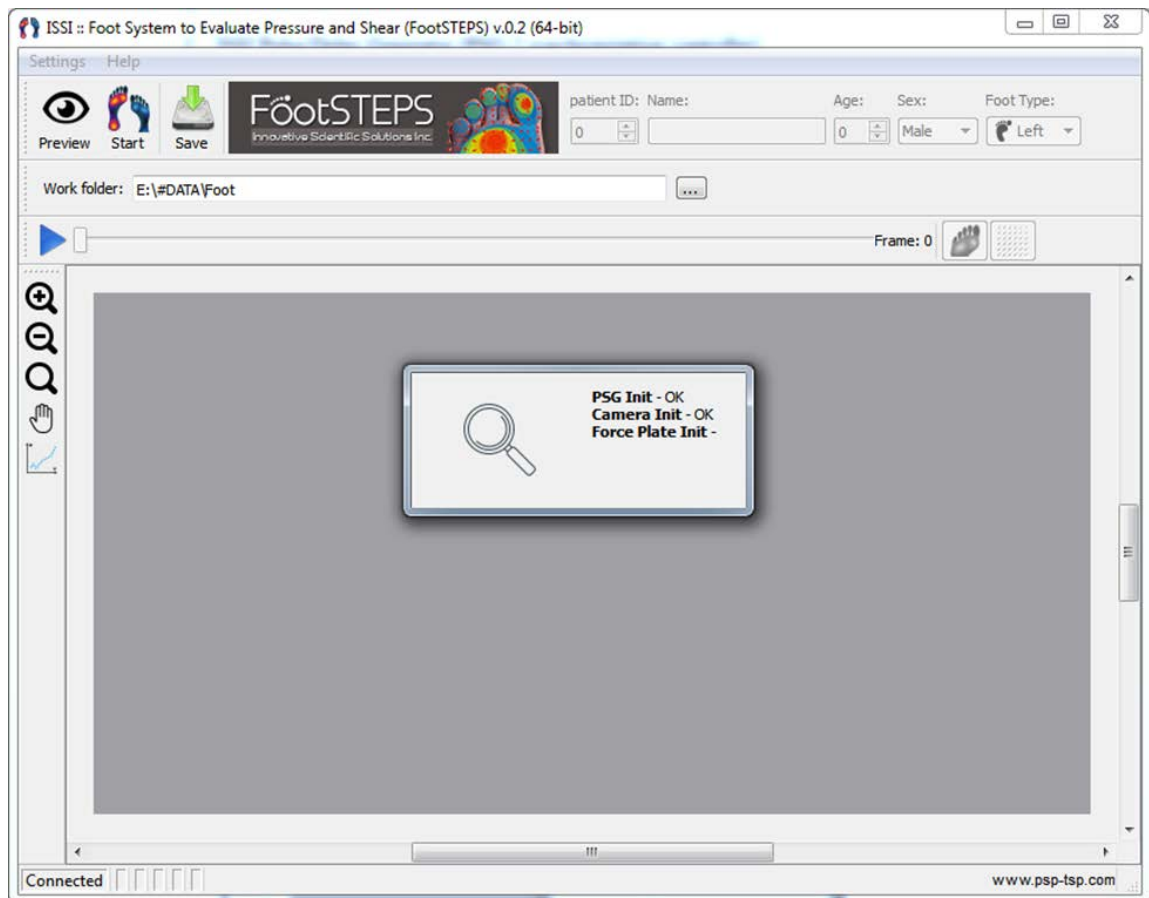


2. **Attach SYNC HFC cable to the SYNC port on the FootSTEPS system box and the SYNC cable for the Force Plate Amplifier.**
3. **Connect the Force Plate Amplifier to the Computer with the USB 2.0 white cable.**

Data Acquisition

1. System Startup

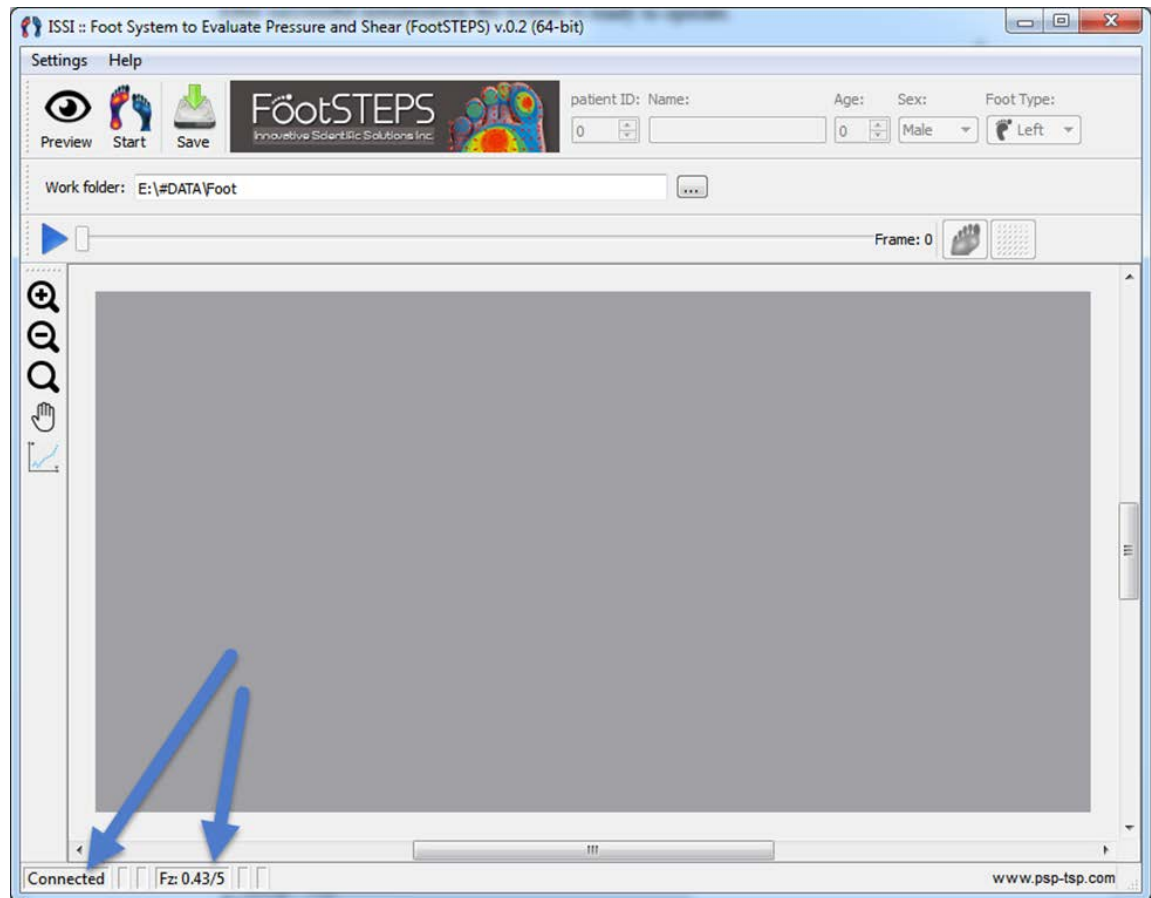
The FootSTEPS acquisition software is designed to collect data, synchronously, from the ISSI S3F imaging system and the force plate. The startup screen is shown below:



After start, the FootSTEPS software will detect and initialize the three key hardware components of the system:

- ISSI Pulse Generator (PSG synchronization controller)
- ISSI Camera (S3F measurement system)
- Force Plate (force measurement platform)

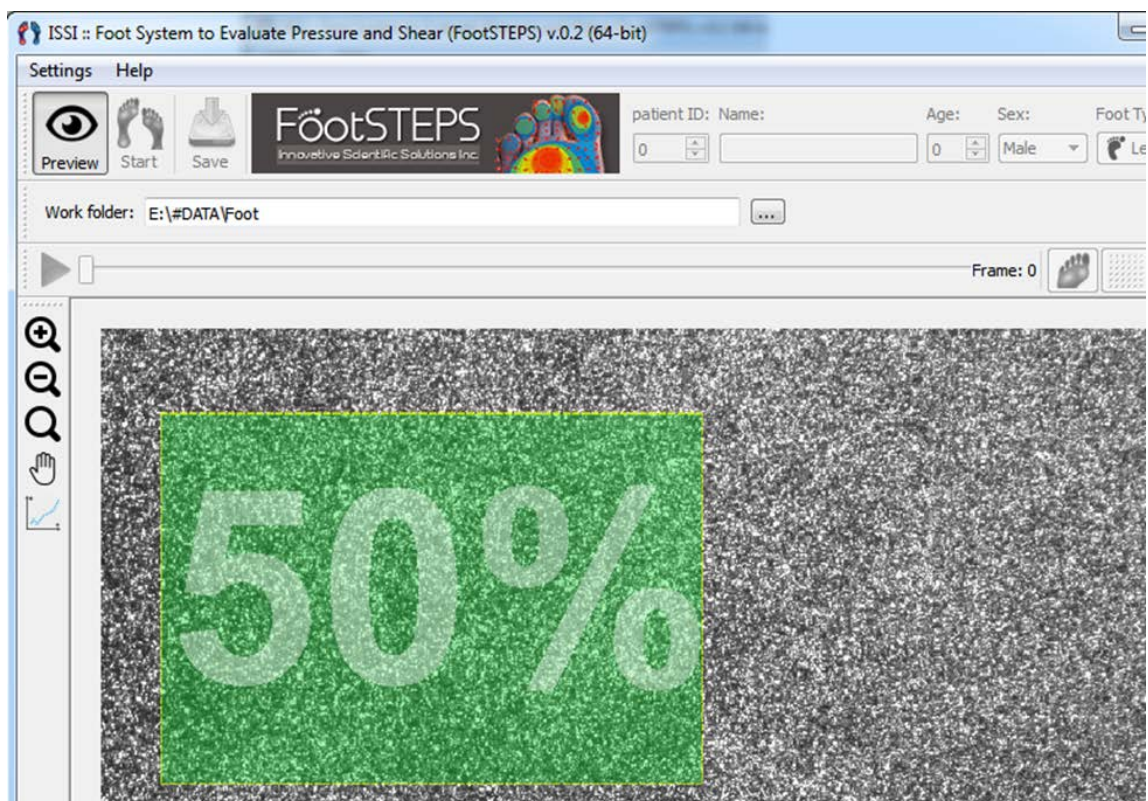
After successful initialization the system is ready to operate.



The top toolbar allows control of the data acquisition process.



Preview Button – Runs image capture synchronously with the LED light source to estimate image view and intensity values. In this mode the user can select a region of interest with the mouse and check the intensity stability and the intensity values, as an initial system check. The image below shows an intensity value of 50% (of the camera's 12-bit full scale range) in the selected region of interest.

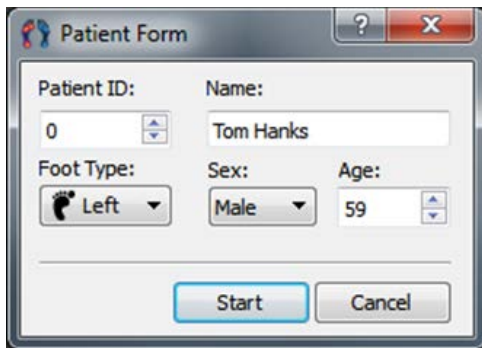


2. Data Acquisition

Start Button – Starts the data (force platform and S3F image data) acquisition process. Before hitting the Start button, the user should select the **Work Folder** – the folder where a subfolder with the patient data will be created.

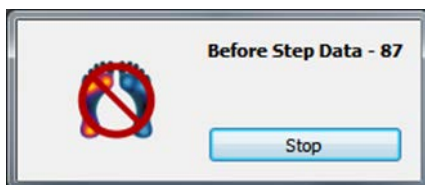
SPECIAL NOTE: Naming Convention of Work Folders and Data Files: Patient foot data folder and file names must not include any special characters; this includes spaces, extra dots, or any character other than alpha-numeric and underscores. For example: patientname.test.tif is not permitted nor patientname xxx xxx.tif. This is important in that the acquisition software allows special characters and does not warn you, however, the FootScripts script writer, discussed later in this manual, will create an erroneous script if it encounters special characters.

After start the **Patient Information** dialog box allows user entry of patient information and which foot (left or right) will undergo data collection. If the confidentiality process requires that patient names and IDs be stored separately, patient ID may be entered in both places.

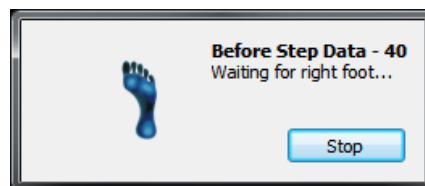
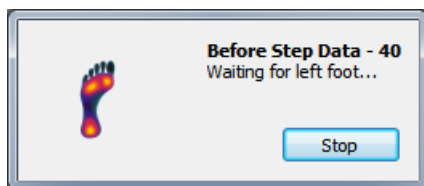


A screenshot of a 'Patient Form' dialog box. It contains fields for Patient ID (0), Name (Tom Hanks), Foot Type (Left), Sex (Male), and Age (59). There are 'Start' and 'Cancel' buttons at the bottom.

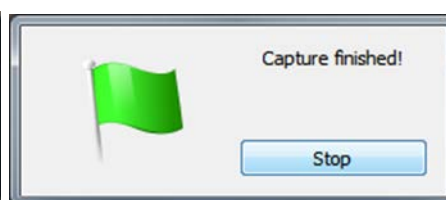
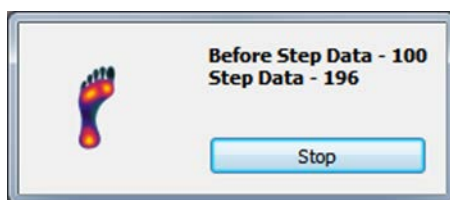
After form completion and activation of the **Start** button, the acquisition process will begin. The first stage will acquire 100 frames of no-load reference data, before the patient step.



Following that the system will switch to waiting for STEP mode and will show what foot step is expected.



After the patient steps on the FootSTEPS platform the acquisition process will continue until the patient is no longer touching the platform or until the maximum number of images is collected.

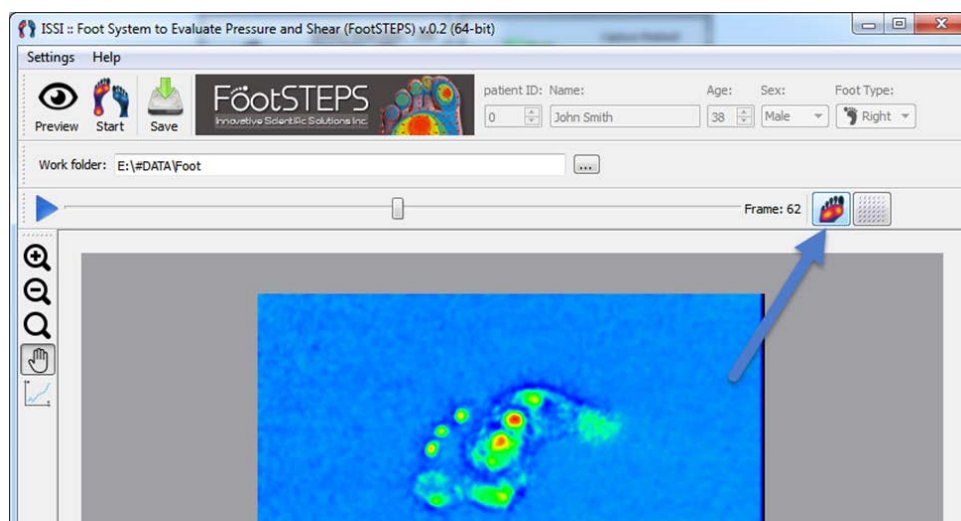


Initially, all data will be acquired and stored in RAM (not on the hard drive!).

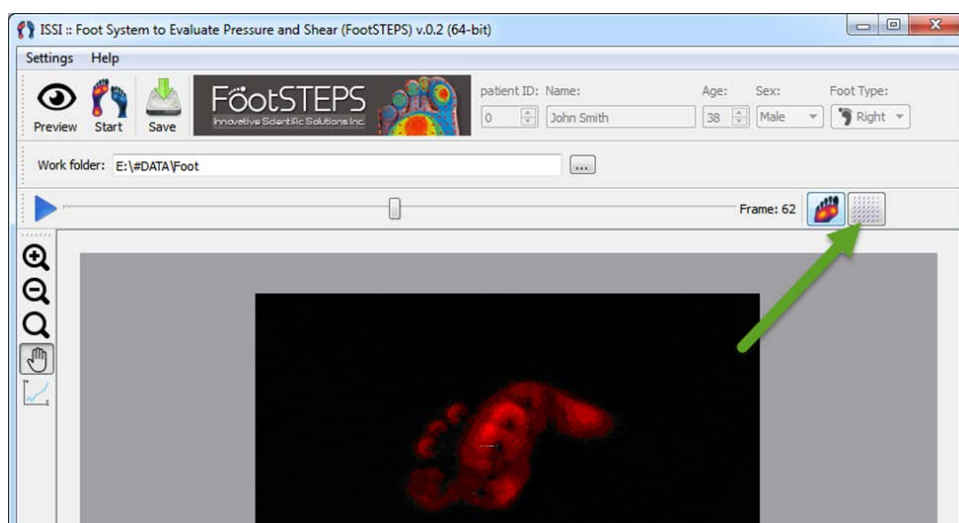
3. Data Preview

After acquisition, the data can be previewed and preprocessed to determine if the user wants to save it or needs to repeat the run. Use the blue **Play** icon to start automatic image playback (~10 frames /sec) from the beginning, or use the slider to see specific frames. The two buttons to the left of the slider provide an estimate of normal pressure and shear for the current image.

Normal load magnitude:

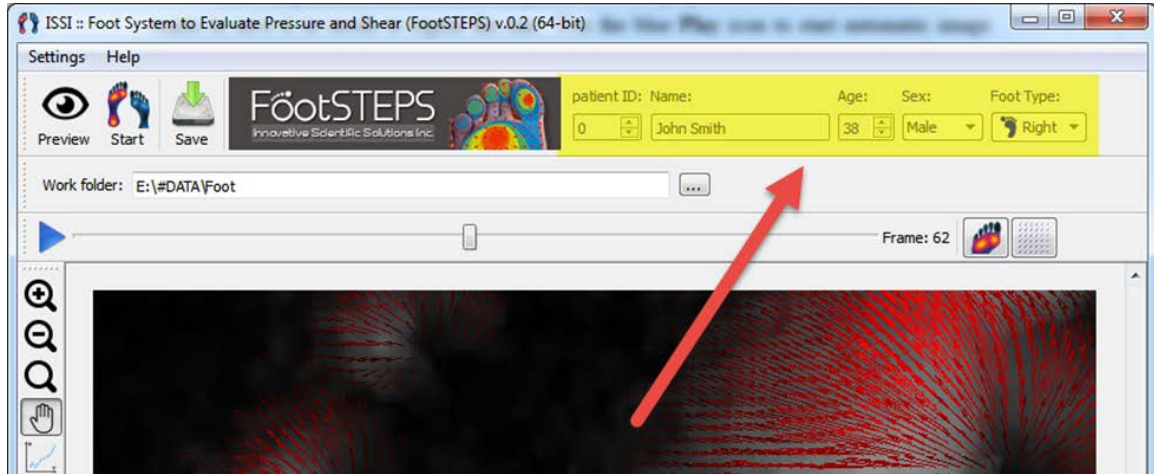


Shear magnitude and vectors:

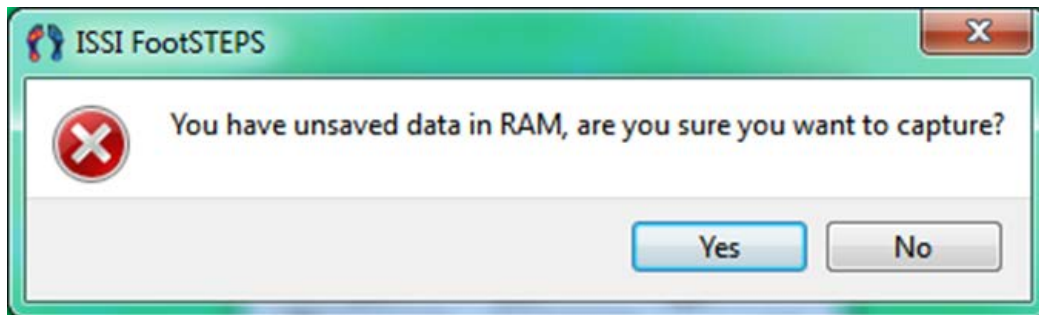


If the data are satisfactory, use the **Save** button to save the captured data. Repeat the above process for additional runs with the patient.

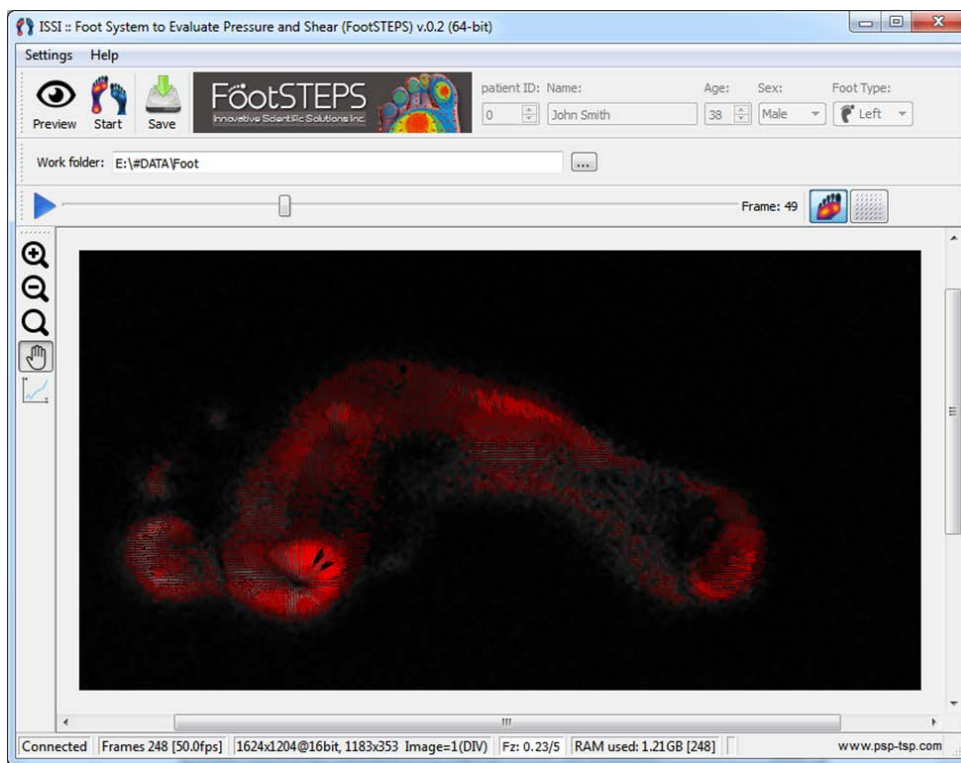
Before saving you can confirm the data set you are working with.



In case you forget to save the collected data and hit the Start button to collect a new run, you will be reminded before you lose unsaved data.



4. Saving the Data



In this example a subfolder will be created in the **Work folder** (E:\#Data\Foot\) with the name "*0_JohnSmith*" where 0 is the *patient ID* and *John Smith* is the *patient name*. The following six files will be created:

1. Patient data text-file (0_JohnSmith_Patient_data.txt)
2. NoStep Averaged TIF-file for Left foot (0_JohnSmith_Left_no_load_avrg.tif)
3. Step multipage TIF-file for Left foot (0_JohnSmith_Left_step_data.tif)
4. NoStep Averaged TIF-file for Right foot (0_JohnSmith_Right_no_load_avrg.tif)
5. Step multipage TIF-file for Right foot (0_JohnSmith_Right_step_data.tif)
6. Foot plate data text-file (0_JohnSmith_Left_forceplate_data.txt)
7. Foot plate data text-file (0_JohnSmith_Right_forceplate_data.txt)

The Patient data file contains information about all data files:

```
[Patient_Data]
ID=0
Name=JohnSmith
Sex=Male
Age=38
```

[Data]

Left_foot_images=148

Left_foot_file=E:\\#DATA\\Foot\\0_JohnSmith\\0_JohnSmith_Left_step_data.tif

Left_foot_average_images=100

Left_foot_average_file=E:\\#DATA\\Foot\\0_JohnSmith\\0_JohnSmith_Left_no_load_avrg.tif

ForcePlate_data_file=E:\\#DATA\\Foot\\0_JohnSmith\\0_JohnSmith_Right_forceplate_data.txt

Right_foot_images=125

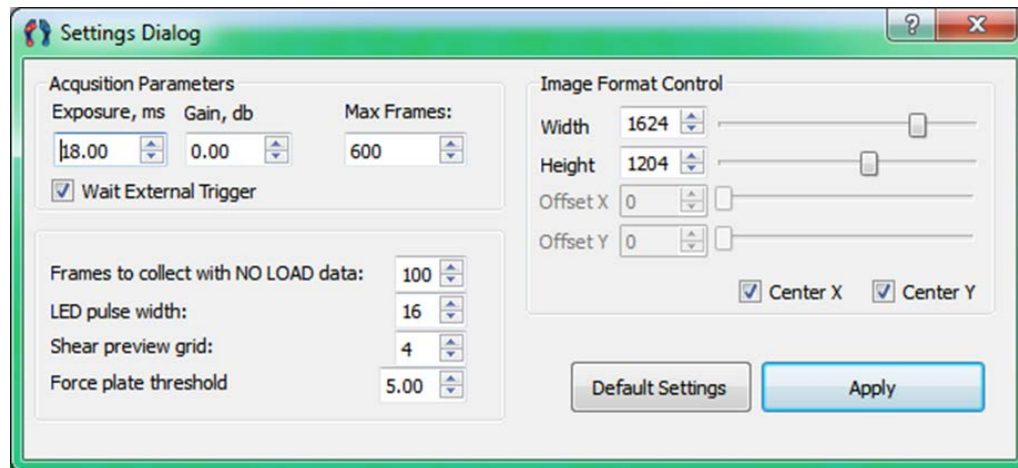
Right_foot_file=E:\\#DATA\\Foot\\0_JohnSmith\\0_JohnSmith_Right_step_data.tif

Right_foot_average_images=100

Right_foot_average_file=E:\\#DATA\\Foot\\0_JohnSmith\\0_JohnSmith_Right_no_load_avrg.tif

5. System Settings

System settings are available to modify several data acquisition parameters, such as camera gain, number of images collected, and so on.



However, inappropriate settings can result in a non-operational system, noisy data, and a number of other undesirable conditions. If you are uncertain about changing the settings, press the **Default Settings** button and then apply them with **Apply** button. Please contact Mr. Nikolay Rogoschenkov at ISSI (nrogoshchenkov@innssi.com, 937-9630-3012, x114) if you believe that a settings change is required but you are not certain how to proceed.

Data Processing

1. Overview

Four software programs are utilized in the processing of foot step data taken with the ISSI FootSTEPS system. This includes: the FootScripts program, the Foot_Analysis_Scheduler program, the FreeFEM++ program, and the FootPlots program.

Step data force reconstruction analysis occurs in a batch mode process controlled by analysis scripts. The main program for writing these analysis scripts is the FootScripts program. This program creates an analysis script for each foot step acquired with the FootSTEPS system. Specific instructions for running this program are located in the next section. Briefly, the user selects the foot step data for analysis, the program finds the starting frame of the foot step and the ending frame of the foot step on the S3F window so that only frames that have foot contact data are processed, and finally an analysis script is created. The steps in the analysis script consist of 1) creating displacement components (measuring the x, y, z displacement of the S3F film caused by the foot contact through cross-correlation and ratiometric analysis), 2) reconstructing the forces that caused the measured displacements by way of a FEM script that calls the freeFEM++ program, and 3) converting the text output force data from the freeFEM program to a binary format for fast loading into the FootPlots program for post analysis.

The script created by the FootScripts program can be launched by the user or can be launched in a batch mode using the Foot_Analysis_Scheduler program. Detailed instructions for using the scheduler are given below, but briefly, the analysis scripts to be processed are loaded into the scheduler and based upon the number of computer cores available for analysis, a series of batch scripts (one for each core selected) is created. For example if four or more cores are available for processing on the analysis computer and the user selects four instances, then four scripts (script0, script1, script2, script3) will be created in a folder entitled BATCH_Foot_Analysis. The user should navigate to this folder and launch each of the scripts, separately. A Command Prompt window will be displayed for each script launched indicating the current processing step. When the analysis is complete, the Command Prompt windows will close and the data is now ready for post analysis by the FootPlots program.

The force reconstruction data is available in two different formats. An ascii text format *.dat and a binary format *.bin. The binary format is used for fast loading by the FootPlots program. Detailed instructions for using the FootPlots program are given below, but briefly, the force reconstruction data is loaded into the FootPlots program for post analysis. The individual data frames are loaded and can be easily displayed by this program. Spatial and temporal plots of the force data are accessible in this program.

The *.dat force reconstruction file should be accessible in MatLab or other graphic packages such as Tecplot. The text format of the force reconstruction *.dat file is listed below. The columns include: X, Y, fx, fy, fz, dx, dy, and dz where X,Y are the spatial locations of the forces (in mm), fx is the reconstructed ML shear, fy the reconstructed AP shear, fz the

reconstructed pressure, dx the displacement-derived ML shear, dy the displacement-derived AP shear, and dz the displacement-derived pressure. All force variables are in pascals.

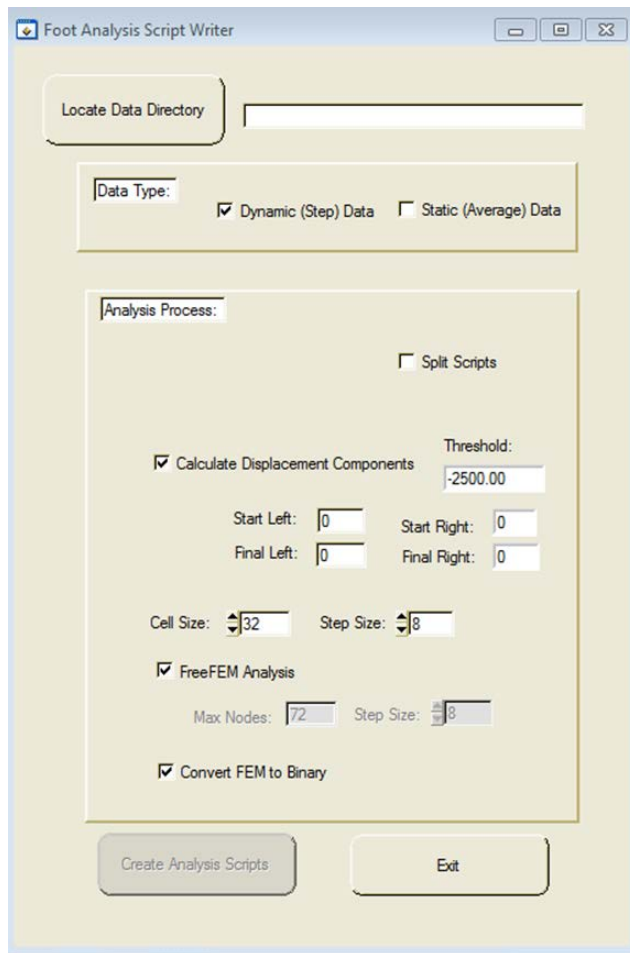
	A	B	C	D	E	F	G	H	I	J
1	TITLE	=	8/26/2010							
2	VARIABLE	=	X	Y	fx	fy	fz	dx	dy	dz
3	ZONE	T="nu=0.4	h=2.3",l=199,J	POINT						
4	0	0	112.995	-2.21E-21	11178.6	0	0	310.143		
5	1.6	0	13.7434	169.839	12420.7	0	0	695.772		
6	3.2	0	-30.9079	261.472	13662.9	0	0	1081.4		
7	4.8	0	-22.3268	248.398	14052	0	0	1197.86		
8	6.4	0	18.8837	218.667	13836.9	0	0	1123.66		
9	8	0	64.6943	222.983	13571.1	0	0	1040.73		
10	9.6	0	2.45627	259.803	13059.3	0	0	915.404		
11	11.2	0	-69.236	245.146	12547.5	0	0	790.074		
12	12.8	0	-19.8559	166.741	11463.6	0	0	754.262		
13	14.4	0	3.09106	131.674	10195.1	0	0	747.325		
14	16	0	-21.4457	110.549	8940.63	0	0	615.791		
15	17.6	0	5.33844	29.7368	7712.96	0	0	243.963		
16	19.2	0	62.1774	-34.6665	6485.3	0	0	-127.866		
17	20.8	0	13.6982	54.1282	6909.82	0	0	42.5704		
18	22.4	0	-29.638	109.302	7464.77	0	0	255.817		
19	24	0	-30.7215	92.6525	7848.64	0	0	350.242		
20	25.6	0	17.4823	64.3762	8069.57	0	0	331.502		
21	27.2	0	76.1729	75.5851	8299.54	0	0	314.088		
22	28.8	0	6.89669	144.858	8613.05	0	0	308.942		
23	30.4	0	-50.7739	156.301	8926.57	0	0	303.797		
24	32	0	-16.6782	114.713	8622.8	0	0	377.466		
25	33.6	0	-1.16196	104.993	8032.43	0	0	487.726		
26	35.2	0	-22.2404	126.356	7532.11	0	0	623.37		
27	36.8	0	0.576431	138.154	7277.38	0	0	828.239		
28	38.4	0	-5.06892	172.933	7022.65	0	0	1033.11		
29	40	0	-8.28162	157.399	7017.27	0	0	972.698		
30	41.6	0	27.6712	136.295	7054.63	0	0	866.81		
31	43.2	0	35.6947	141.848	7178.1	0	0	713.083		
32	44.8	0	-6.94786	143.466	7411.61	0	0	498.226		
33	46.4	0	-16.4802	101.879	7652.86	0	0	291.953		
34	48	0	-2.68812	110.845	8203.98	0	0	429.014		
35	49.6	0	12.6307	131.438	8755.1	0	0	566.076		
36	51.2	0	11.0817	152.958	8993.95	0	0	609.475		
37	52.8	0	-9.30367	159.303	9032.96	0	0	592.931		

2. FootScripts Program

The FootScripts program creates the batch script for analyzing step data from the ISSI FootSTEPS system. The program looks for a minimum of four files in each step folder. The files include the step no-load data, the step load data, the step force plate data, and the patient information. The step data can be either a left or right foot step, but at least one of them must be present for processing. The program creates the analysis script via the following steps: 1) calculate displacements of S3F film by correlation and image ratioing, 2) reconstruct the

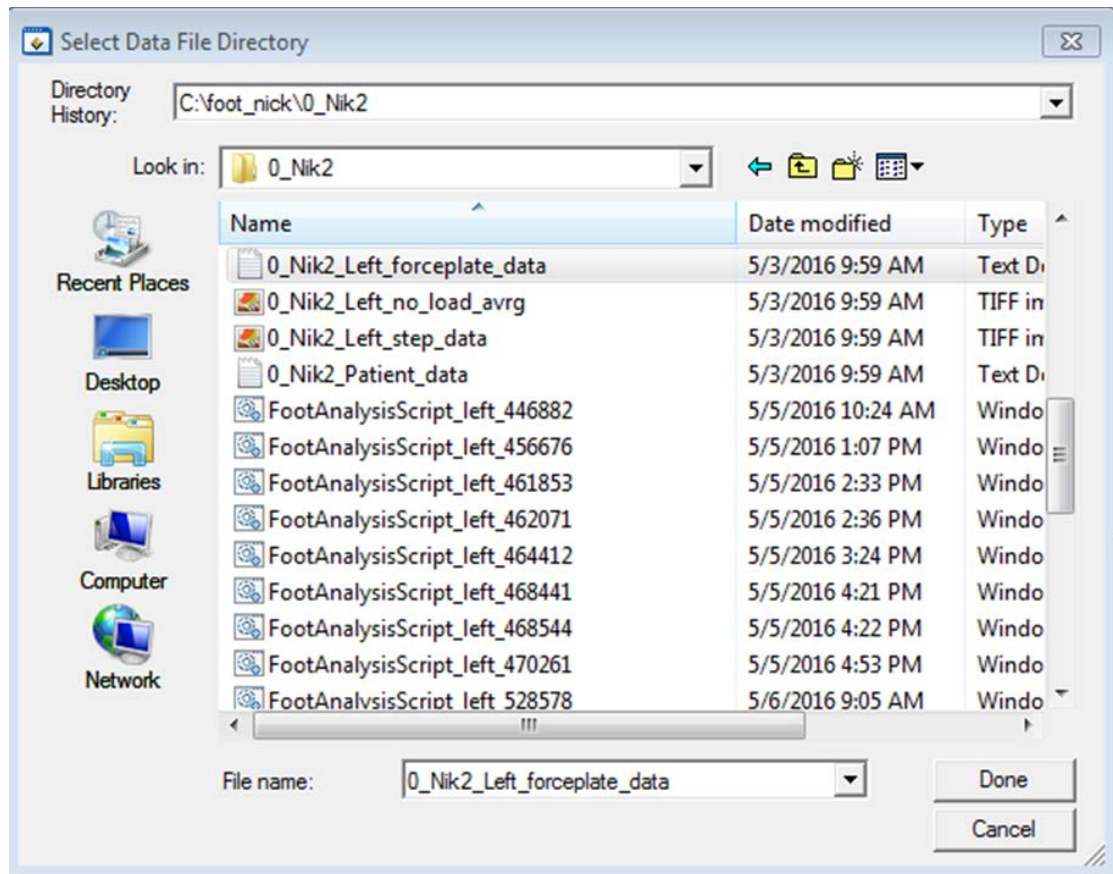
forces needed to match the measured S3F film displacements using a freeFEM++ script, and 3) convert force data from text to binary format for fast loading by the FootPlots program. The program can handle either dynamic (step) or static (calibration) data files.

To start the process, the user should locate the FootScripts program and launch it. The Foot Analysis Script Writer will then appear. The user should select the Locate Data Directory button at this point to identify which data set is going to be analyzed.

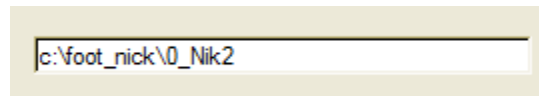


The screenshot shows the 'Foot Analysis Script Writer' dialog box. It has a title bar with standard window controls. The main area contains several sections: a 'Locate Data Directory' button at the top left; a 'Data Type' section with radio buttons for 'Dynamic (Step) Data' (selected) and 'Static (Average) Data'; an 'Analysis Process' section with a 'Split Scripts' checkbox, a 'Calculate Displacement Components' checkbox (selected) with a 'Threshold' field set to '-2500.00', and input fields for 'Start Left', 'Start Right', 'Final Left', and 'Final Right' (all set to '0'); 'Cell Size' and 'Step Size' spinners (set to 32 and 8 respectively); a 'FreeFEM Analysis' checkbox (selected) with 'Max Nodes' and 'Step Size' fields (set to 72 and 8 respectively); and a 'Convert FEM to Binary' checkbox (selected). At the bottom are 'Create Analysis Scripts' and 'Exit' buttons.

After selection of this dialog button, the program will display a Select Data File Directory dialog, and the user should navigate to the location of the data to be processed. Once this is accomplished, select the Done button and proceed to select the scripts to be written.



Note that the user-selected data file name is then displayed in the adjacent text box.

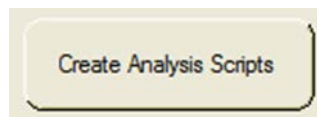


Next the user should decide whether the script will be split into four scripts or be kept as a single large one. As a rule of thumb, if a single step is being processed and the analysis computer has four or more cores, it is advisable to split the script to take advantage of the multiple cores. However, if multiple steps are to be analyzed at the same time, it is advisable not to split the script and just make one large script for each step and run as many steps as there are computer cores in the batch mode.

☐ Split Scripts

The user should now select which analysis steps will occur, including Calculate Displacement Components, FreeFEM Analysis, and Convert FEM to Binary. Because all steps are necessary for post-analysis of the step data with the FootPlots program, it is advised that the default settings be used (all processes selected).

Once the user has selected the Data Directory location and the analysis to be accomplished, the Create Analysis Scripts button becomes active and should be selected to create the analysis script.



The analysis script will be created in the Data Directory selected by the user. A folder named Components_Left_xxxxxx (and/or Components_Right_xxxxxx) will be created and inside this folder will be a FEM_xxxxxx folder which will include the FEM force reconstruction text and binary file versions. Note the xxxxxx is a unique number generated at the time of writing the script by the FootScripts program. The FEM binary files are the ones used by the FootPlots software described in the Data Visualization and Analysis section.

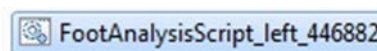
During the process of creating the analysis script, the program determines when the step actually occurred relative to the triggering of the force plate. This procedure is necessary since the force plate and the foot sensor acquisitions can be triggered prior to the foot making contact with the S3F image sensor. This selection process is affected by the threshold setting shown in the threshold numeric. The default value of -2500 should be good for most step data. For dynamic calibration data, this value should be lowered to ~ -500. Note, that the threshold is a negative value. It will take several seconds to find the beginning and ending foot contact frames. The image frame for the beginning of the step and for the end of the step are displayed in the section below for the left and/or right foot.

Threshold:

Start Left: <input type="text" value="1"/>	Start Right: <input type="text" value="0"/>
Final Left: <input type="text" value="78"/>	Final Right: <input type="text" value="0"/>

The program will display a busy cursor while it is in the process of finding the beginning and final step frames and as it writes the analysis script to the step data file. Once this process is complete, as indicated by the return of the normal cursor, the user can either navigate to a new step and write another analysis script or exit the program.

To start the batch analysis process, the user should locate the FootAnalysisScript_Left_xxxxxx (and/or FootAnalysisScript_Right_xxxxxx) command script and launch it by double clicking. Note that if the scripts were split, then four FootAnalysisScriptA, FootAnalysisScriptB, FootAnalysisScriptC, and FootAnalysisScriptD scripts will be created. To start this analysis, launch each of the four files separately. When the analysis is complete, the display window showing the progress of the analysis will disappear. The analysis should now be complete and

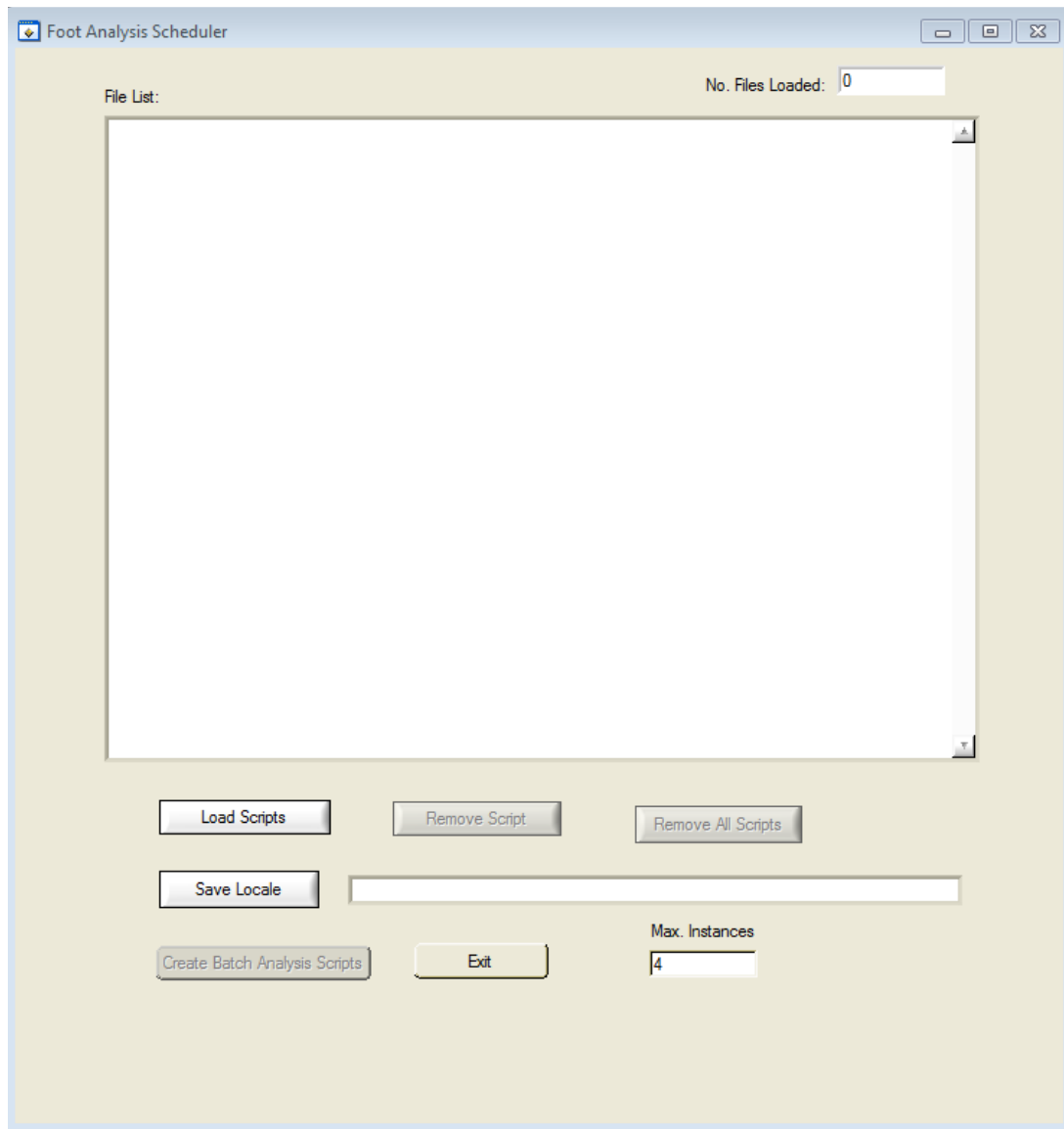


the data ready for any post-processing. This can be accomplished with the FootPlots program or by a user-developed Matlab program.

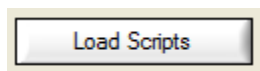
3. **Foot_Analysis_Scheduler Program**

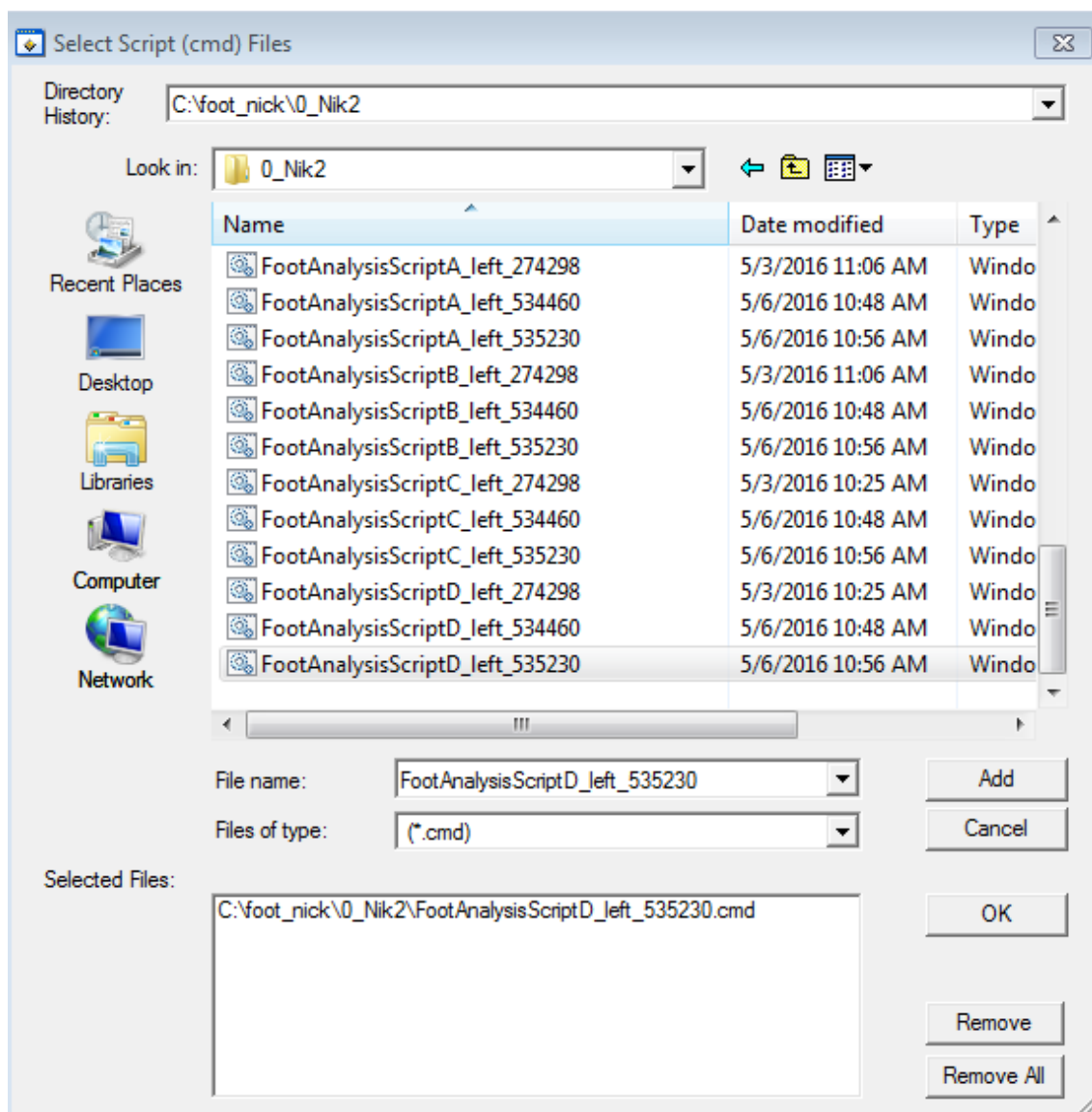
The Foot_Analysis_Scheduler software allows the user to select and schedule the analysis scripts for batch mode processing of the foot step data. This program allows the user to select the scripts to be processed (generated by the FootScripts program), determine the number of instances (cores) to be used in the analysis and creates a series of batch analysis scripts which the user will launch for batch step analysis. The reason for this program is that the analysis scripts created by the FootScripts program requires the user to launch them individually and thus the user must continuously monitor the analysis progress over an extended period of time. However, all scripts cannot be processed at the same time. This program combines the individual scripts into a batch file based on the number of cores available in the analysis computer. For example, a 3 core machine can run two instances of the batch analysis, while a 5 core can run 4 instances, and so forth. As an example, to process twenty steps in a 5 core machine, the twenty individual scripts would be loaded into the Foot_Analysis_Scheduler program with 4 instances being selected, and a BATCH_Foot_Analysis folder containing 4 scripts (one for each instance) will be created. The user would then launch each of the 4 scripts in the analysis folder which would start the processing of all twenty steps.

To start the Foot_Analysis_Scheduler, find the program folder and launch the program. The dialog shown below will appear.



The next step is to select the load scripts button and the load file dialog will appear.

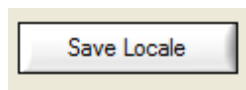




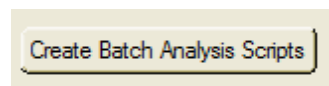
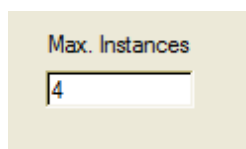
Navigate to the foot step analysis scripts that were created by the FootScripts program and select the scripts you wish to process. This process should be repeated for each script you wish to analysis and when complete select the OK button. The script names will then be loaded into the Foot_Analysis_Scheduler dialog along with the number of files loaded by the user.



The user should next select the Save Locale button and navigate to the folder in which the user wishes to save the analysis scripts and select the Done button.



The user should next select the number of instances to be created in the BATCH_Foot_Analysis folder. To actually create the batch analysis scripts, select the Create Batch Analysis Scripts button. The batch analysis scripts are written to the BATCH_Foot_Analysis folder. Exit the Foot_Analysis_Scheduler and then locate the BATCH_Foot_Analysis folder and then launch each of the script files (script0....scriptX, where X is the number of instances -1) and the analysis will start.



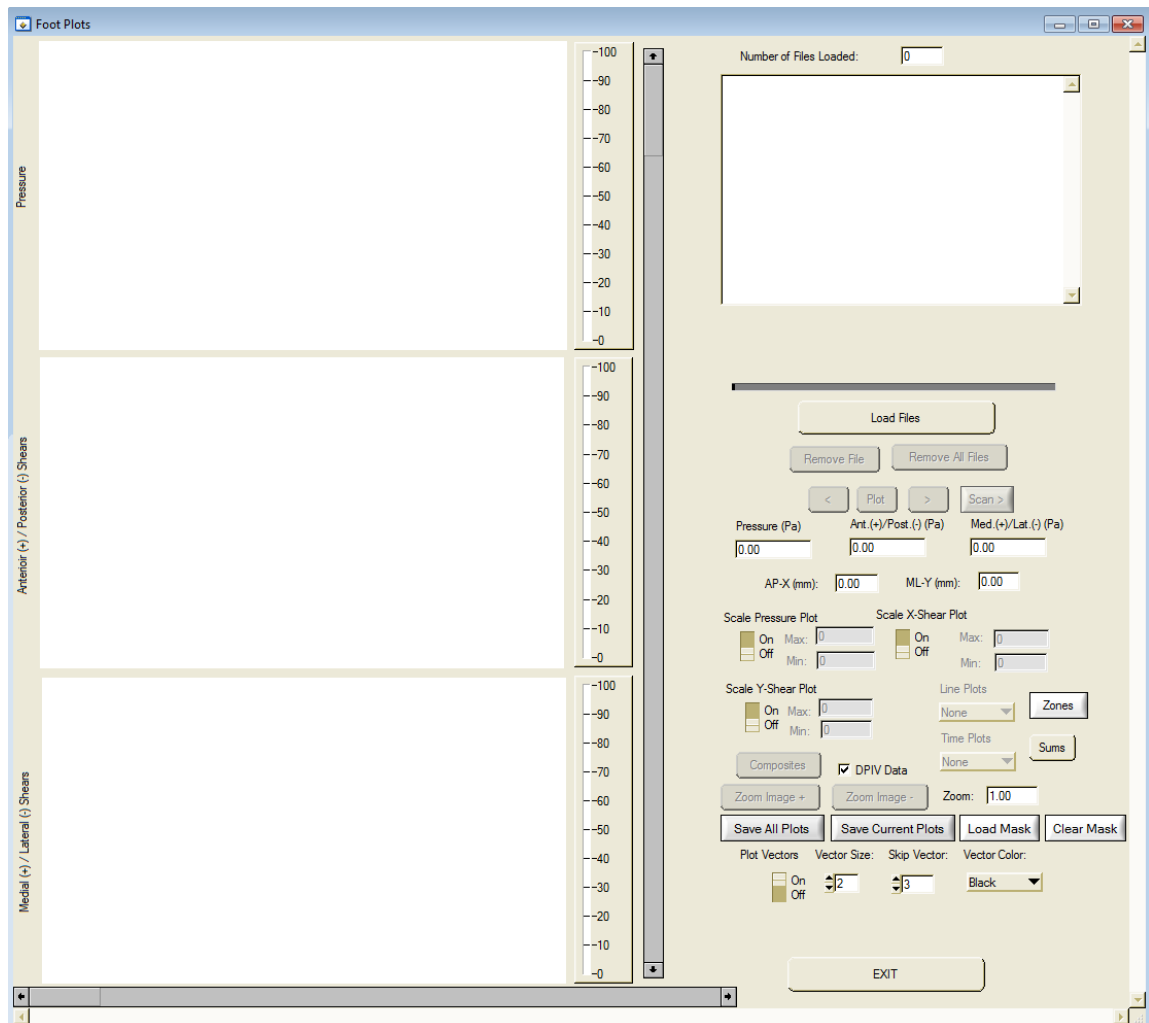
Name	Date modified	Type	Size
script0	5/3/2016 10:25 AM	Windows Comma...	1 KB
script1	5/3/2016 10:25 AM	Windows Comma...	1 KB
script2	5/3/2016 10:25 AM	Windows Comma...	1 KB
script3	5/3/2016 10:25 AM	Windows Comma...	1 KB

Each script, when launched, will open a Command Prompt window which indicates that the analysis is currently underway. When finished, all Command Prompt windows will close.

Data Visualization and Analysis

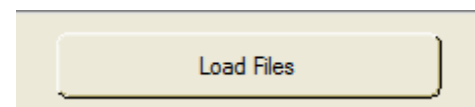
1. Starting FootPlots

Once the foot data have undergone the reconstruction process, they can be visualized with the FootPlots program. To start the program navigate to the FootPlots executable, and launch the program. The program will display the dialog shown below.



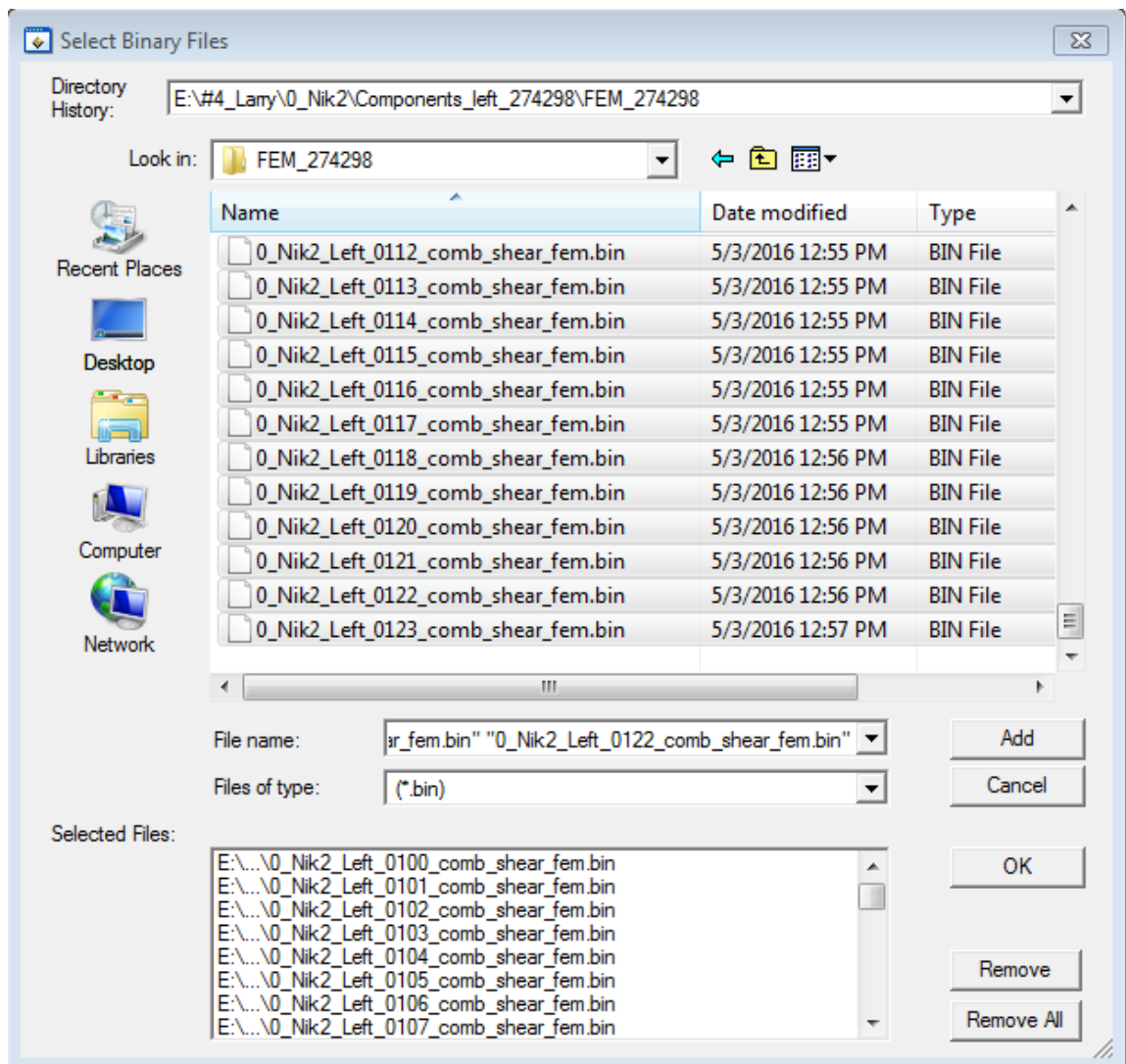
2. Loading FEM Binary Files

The first step is to load the FEM binary result files using the **Load File** button.



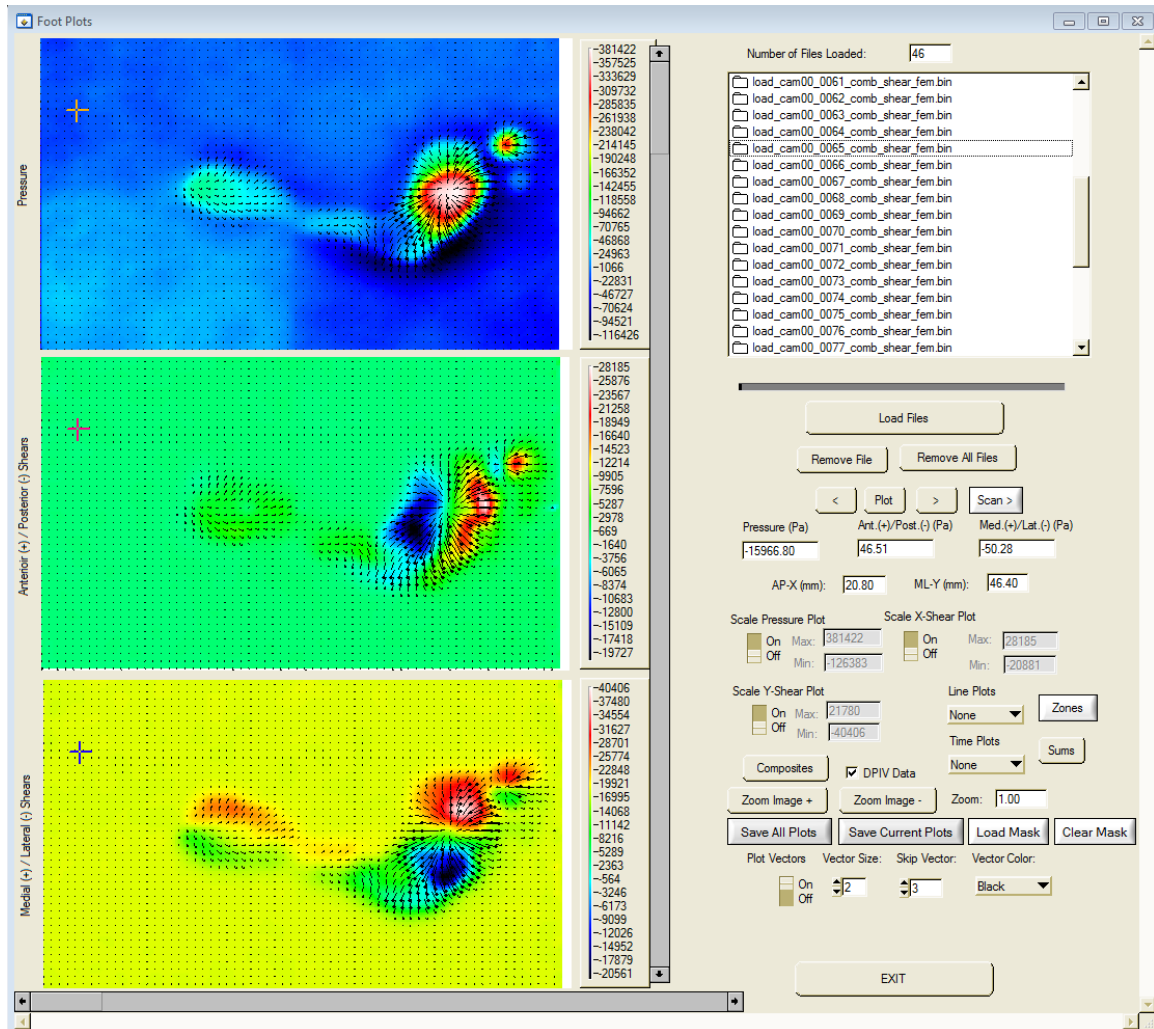
The program will immediately display the **Select Vector Files** dialog that asks the user to find the FEM binary files to be loaded. The user should navigate to the FEM binary files,

select the files (frames) to be loaded and hit the **Add** button on the dialog to select the files and then the **OK** button to load the files into the FootPlots program. The location of the FEM binary files will be the data directory selected when running the FootScripts program. A folder named Components_Left_xxxxxx (and/or Components_Right_xxxxxx) was created and inside this folder is a FEM_xxxxxx folder which includes the FEM force reconstruction text and binary file versions. The FEM binary files are the ones used by the FootPlots software.



The FootPlots program will display the pressure, anterior/posterior shear, and medial/lateral shear results for the selected frame (at the cursor location), display the total number of files loaded, display a list box containing the names of the files loaded, and activate all program functions.

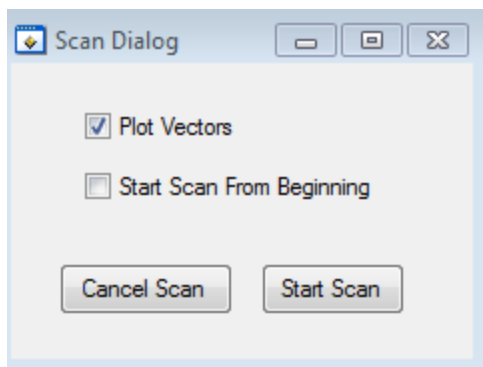
Number of Files Loaded: 46



3. Displaying Data Files

The foot-step results can be displayed in several ways; a complete scan through all of the data can be made by selecting the **Scan >** button. A dialog will appear asking the user to select whether the vectors will be plotted and whether the scan should start from the beginning frame. The user should then select the **Start Scan** button, and the entire loaded result files will be displayed. If the option to turn off the vector plot is chosen, the speed of the display will be increased.

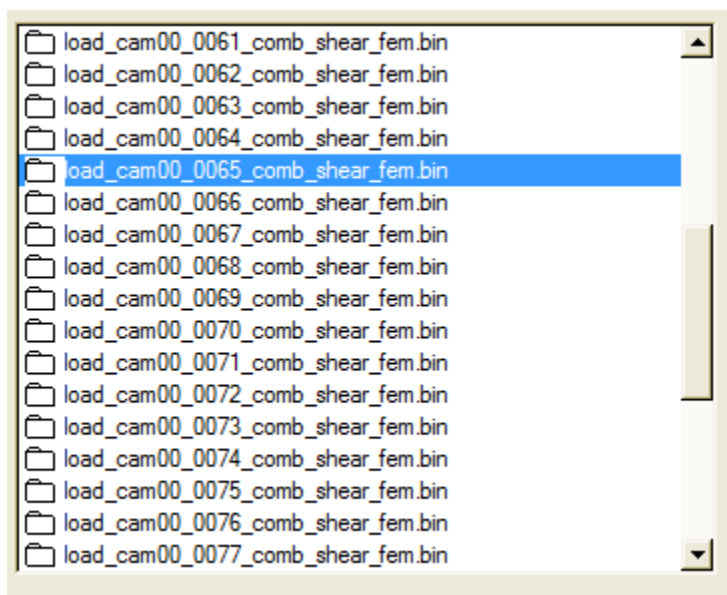
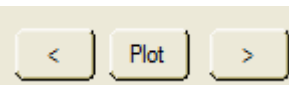
Scan >



The scan can be halted at any point by selecting the **Stop** button.



Individual frames can be plotted by selecting the <, **Plot**, or > buttons. The < button will display the previous frame; the **Plot** button will display the currently selected frame; and the > button will display the next frame. Note that an arbitrary frame can be plotted by simply highlighting the frame by placing the cursor on the name, left-clicking the mouse, and then hitting the **Plot** button.



The initial display of the FEM data is autoscaled, and the max's and min's of the various parameters are shown in the **Scale** numeric boxes. To rescale the plots, select the parameter to be scaled [pressure, anterior(+)/posterior(-) shear, or medial(+)/lateral(-) shear] turn scale from **Off** to **On**, and manually enter the scale



max and min values. Then hit the **Plot** button to update the displayed plots.

Scale Pressure Plot Scale Anterior (+)/Posterior (-) Plot

☒ On Max: 242586 ☒ On Max: 17072
☐ Off Min: -70877 ☐ Off Min: -9823

Scale Medial (+)/Lateral (-) Plot Line Plots

☒ On Max: 20756 None ▼ Zon
☐ Off Min: -27803 Time Plots

4. Making Composite Images

Composite frames can be constructed by selecting the **Composites** button. The composite images/frames are added at the end of the data set and are called **Composite – Sum** and **Composite – Peak**. Composite-Sum is the average value for all of the data loaded, and Composite – Peak is the peak value for all of the data loaded at each x-y location. The composite data is used to determine the foot zones (to be discussed later).



5. Displaying Individual Data Values

The value of the pressure or shear components for the displayed frame can be determined by placing the cursor at the desired point of interest and reading the numerical displays. The pressure, anterior/posterior shear, medial/lateral shear, and the AP-X – ML-Y locations of the current cursor position will be displayed in the appropriate numeric box.

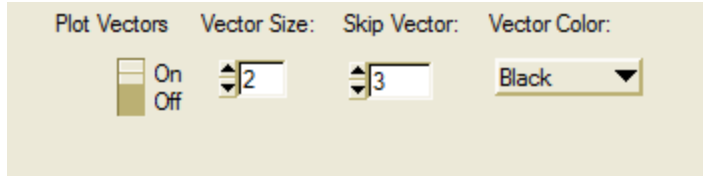
Pressure (Pa) Ant. (+)/Post. (-) (Pa) Med. (+)/Lat. (-) (Pa)

-21615.50 -127.21 -36.86

AP-X (mm): 96.00 ML-Y (mm): 99.20

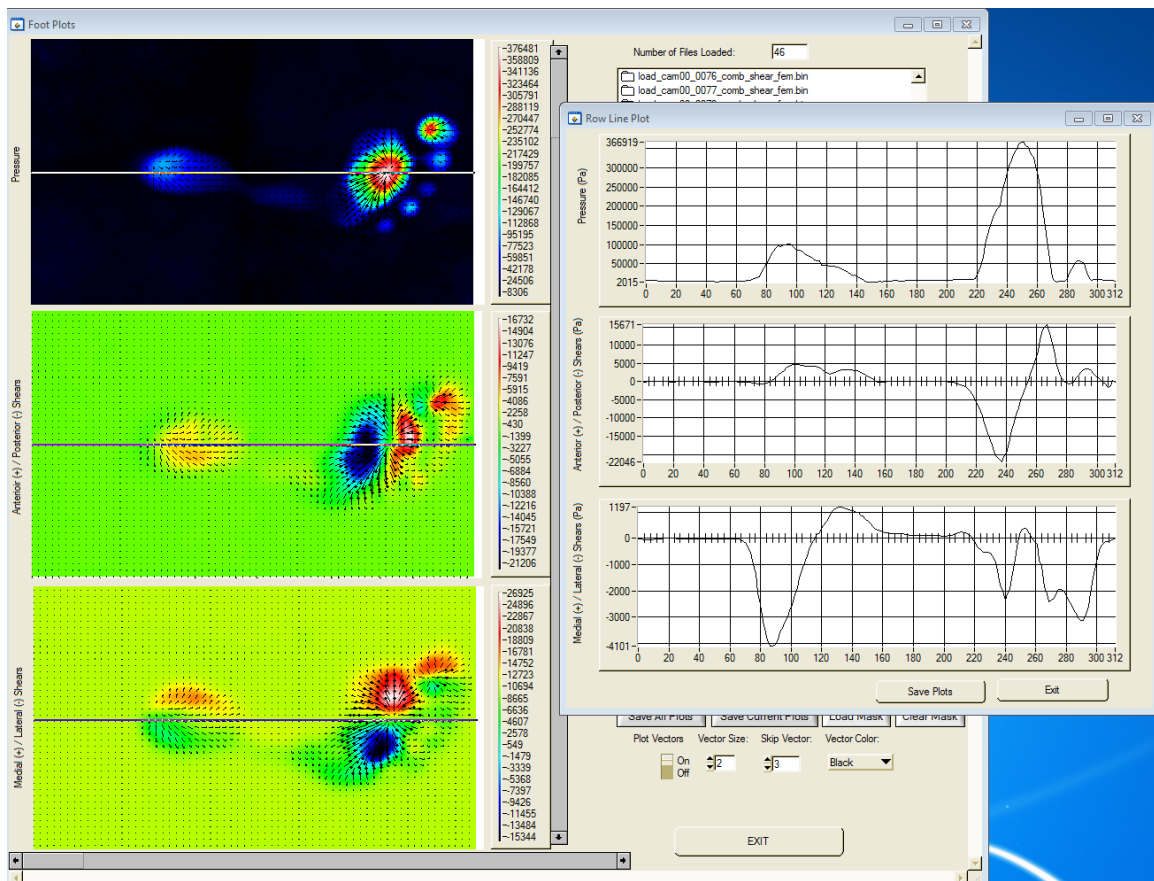
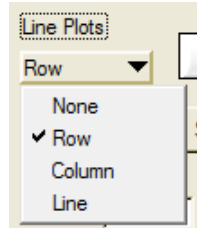
6. Using Vector Plot Controls

The vector plot controls allow the user to control the display of the vector information. Because the vector density is high, it is important that not all vectors be displayed since this will overwhelm the image displays. In some instances the user may wish to forgo the vector plots all together in order to increase the speed of an image scan or select the zones for analysis. Vector plots can be turned on and off with the **Plot Vectors** toggle switch. The displayed vector size (**Vector Size**), number of vectors to skip (**Skip Vector**), and vector color (**Vector Color**) can be user selected. The default values for the vector plots are shown below.

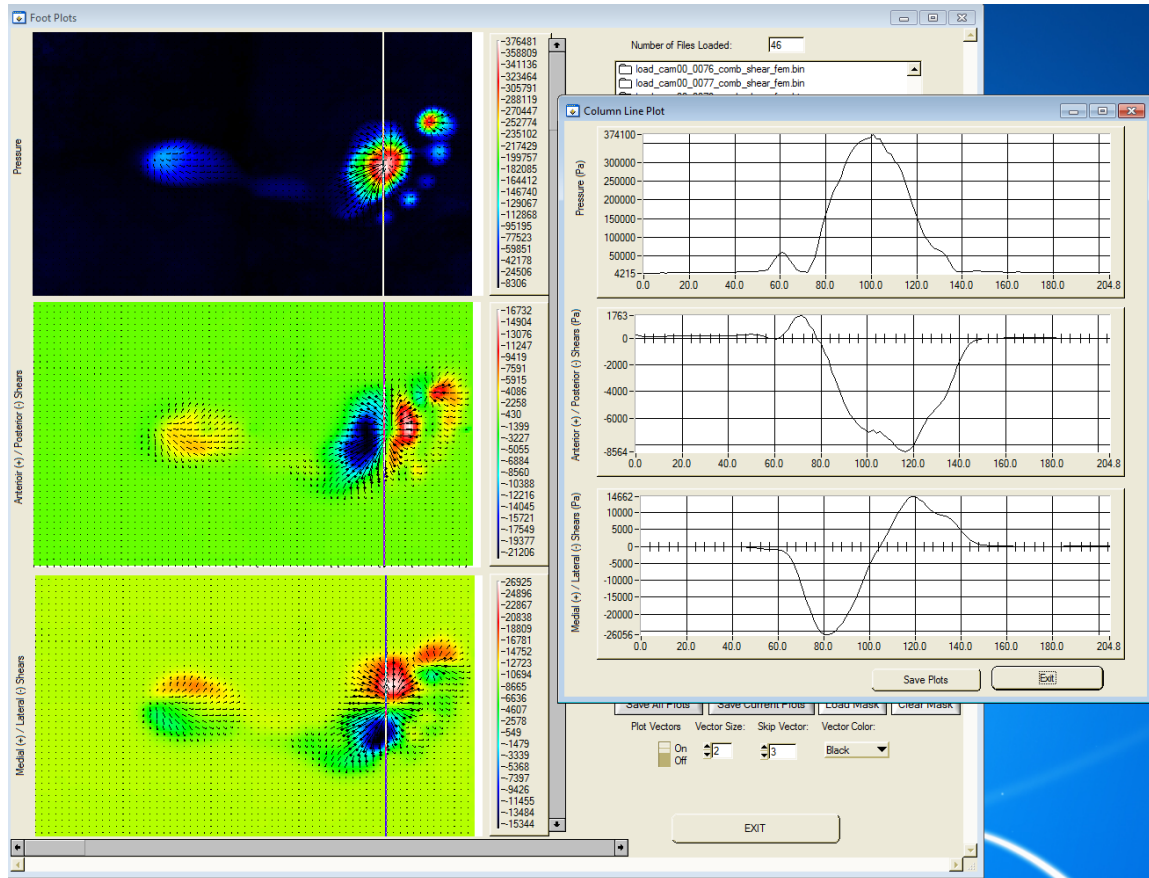
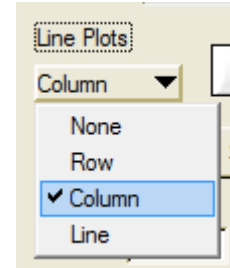


7. Displaying Line Plots

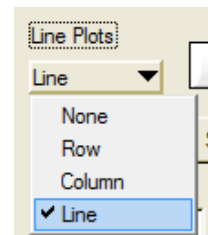
The pressure, anterior/posterior shear and medial/lateral shear can be displayed in line plots for the currently displayed data frame by selecting the type of line plot to display from the **Line Plots** pulldown. The options are 1) **Row**, 2) **Column**, and 3) **Line** (freehand line). Selecting a **Row** line plot will result in the display shown below. The user should click on the desired row to be displayed and the Row Line Plot graph will appear. To save the plot information, the user should select the **Save Plots** button, and an ascii excel file will be created.

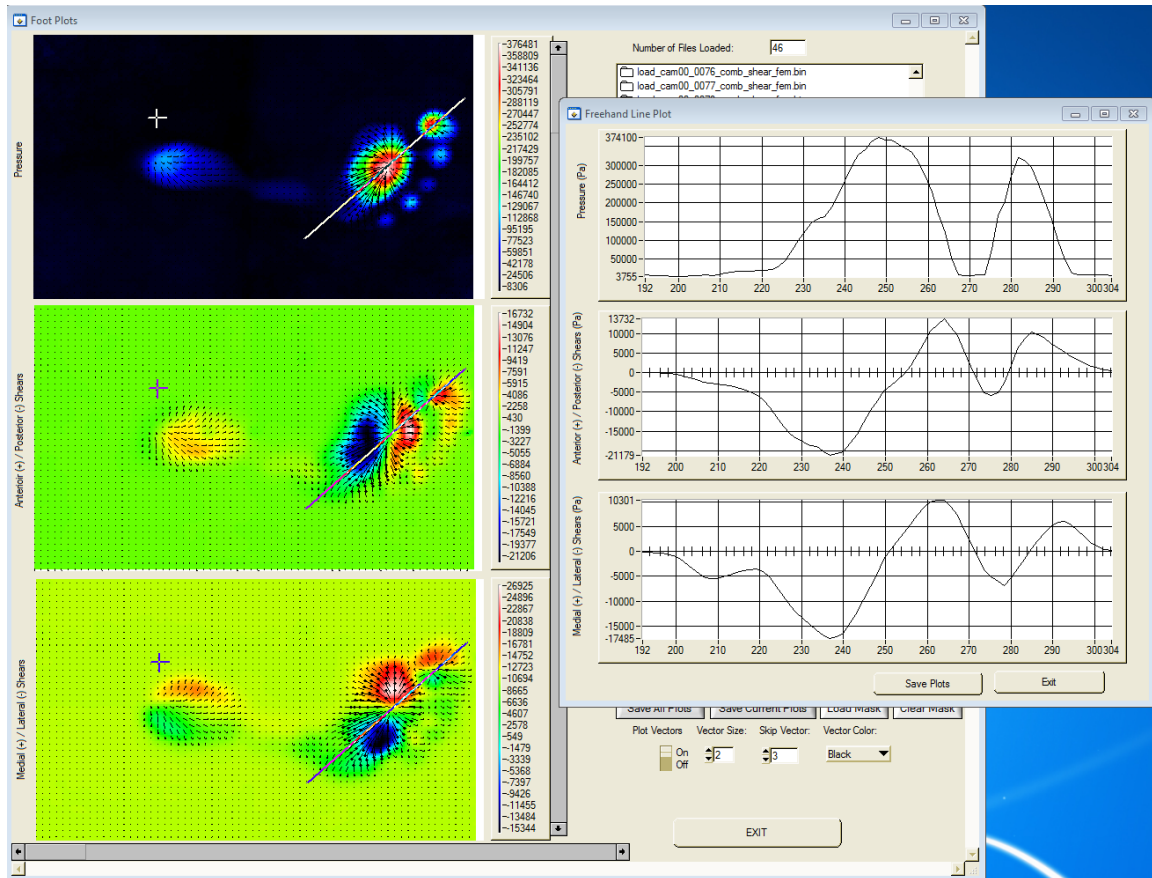


Selection of the **Column** line plots causes the data along the user selected column to be graphed. As with the Row line graph, the user has the option to save the graphical data by electing the **Save Plots** button.



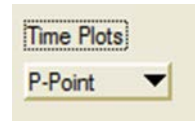
The third line plot option is a freehand line. An arbitrary line can be drawn on any display by moving the cursor to the start position, clicking and holding the left mouse button, moving the cursor to the line endpoint, and releasing the left-mouse button. A line will be displayed and the associated data graphed. As with the other line plots, the user can save the data by selecting the **Save Plots** button.

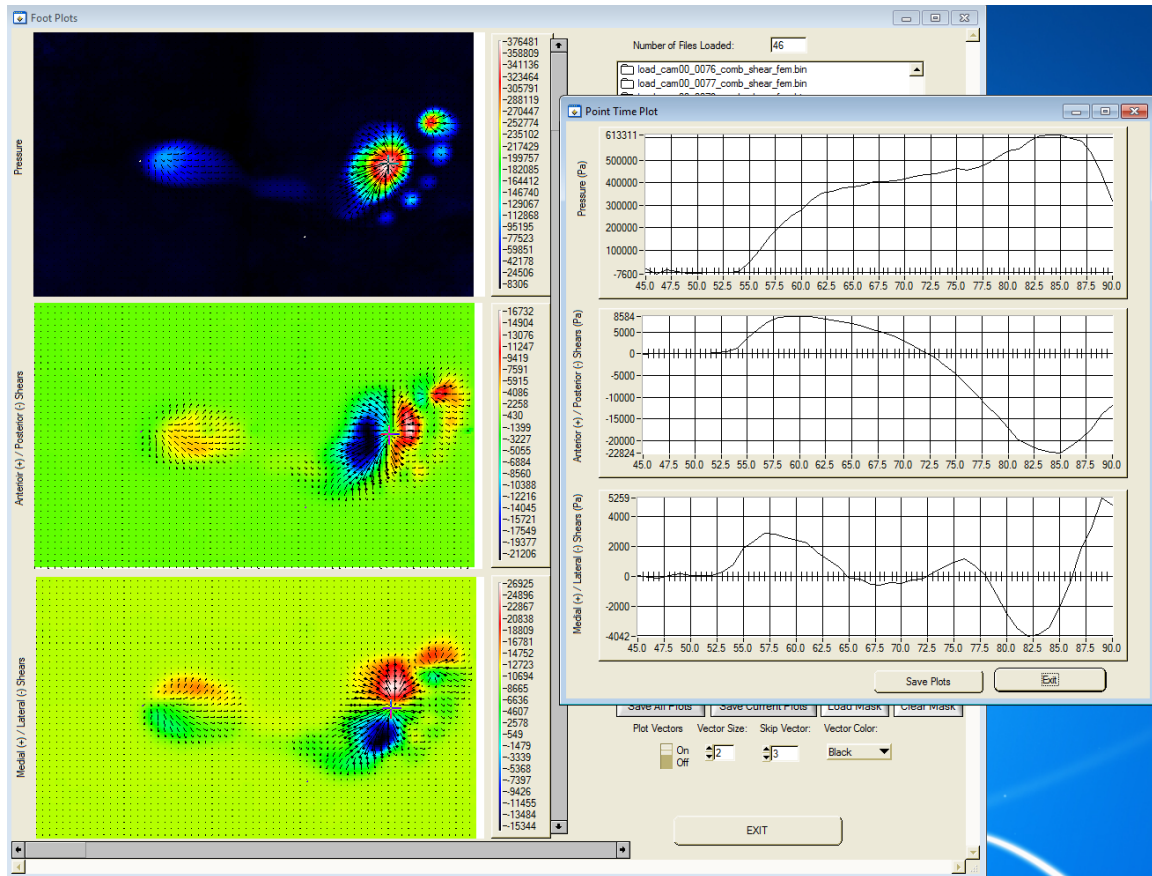




8. Displaying Time Plots

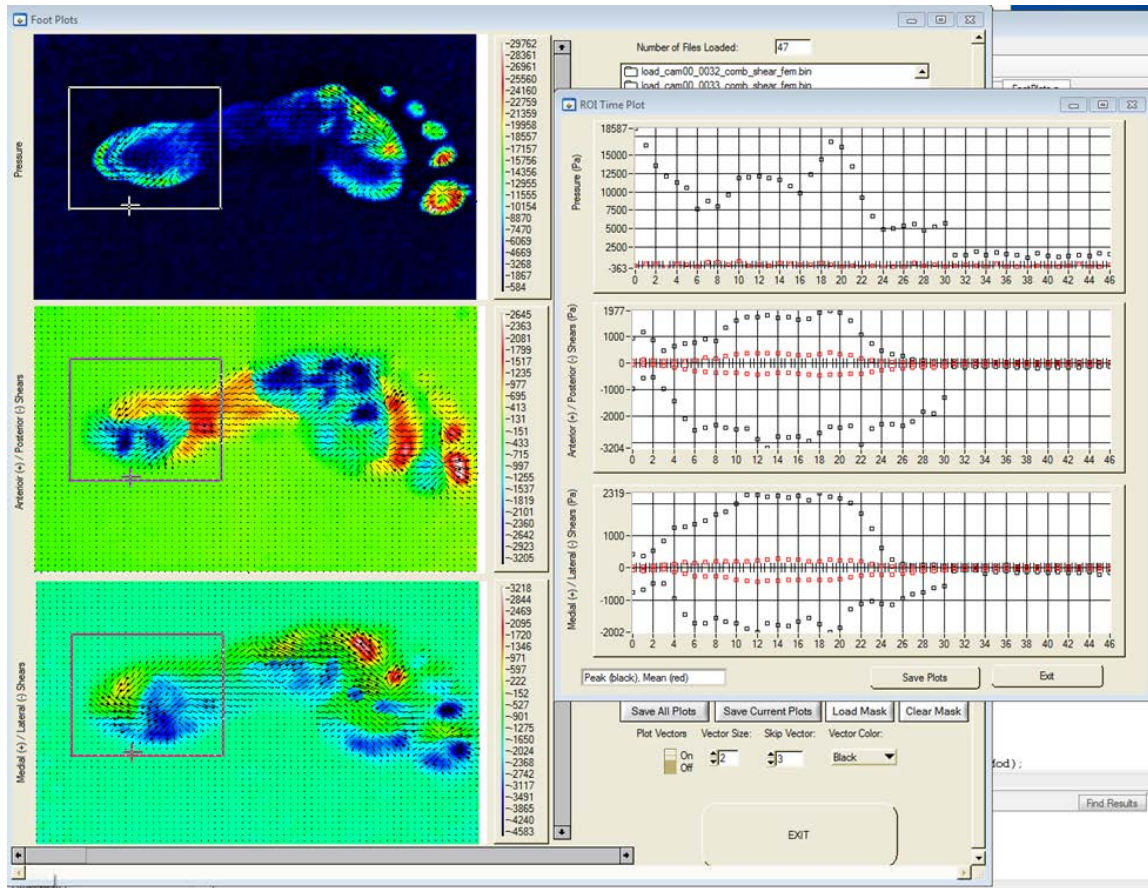
Data can also be displayed as a function of time for each of the loaded frames by selecting the **Time Plots** pulldown. The available time plots are 1) **Point**, 2) **ROI** (Rectangular Region of Interest), and 3) **IROI** (Irregular Region of Interest). The **Point** time plot is illustrated below. Here the time history of the pressure, anterior/posterior shear, and medial/lateral shear are displayed for a user selected point as a function of time (frames loaded into FootPlots). As with the line plots, the graphical data can be saved in an ascii excel file if desired.





The **ROI** time plot is illustrated below. Here the user selected **ROI** is shown both for the peak values (black) and the average values (red). Once the **ROI** pulldown is activated, an **ROI** can be selected by moving the cursor to the upper left hand point of interest, clicking and holding the left mouse button, expanding the rectangle to cover the entire region of interest, and then releasing the left mouse button. The graphics data corresponds to the mean and peak values for that **ROI**. Note that the user can save the data as an ascii excel file. The saved data includes an ascii excel file that provides the coordinates of the **ROI**.

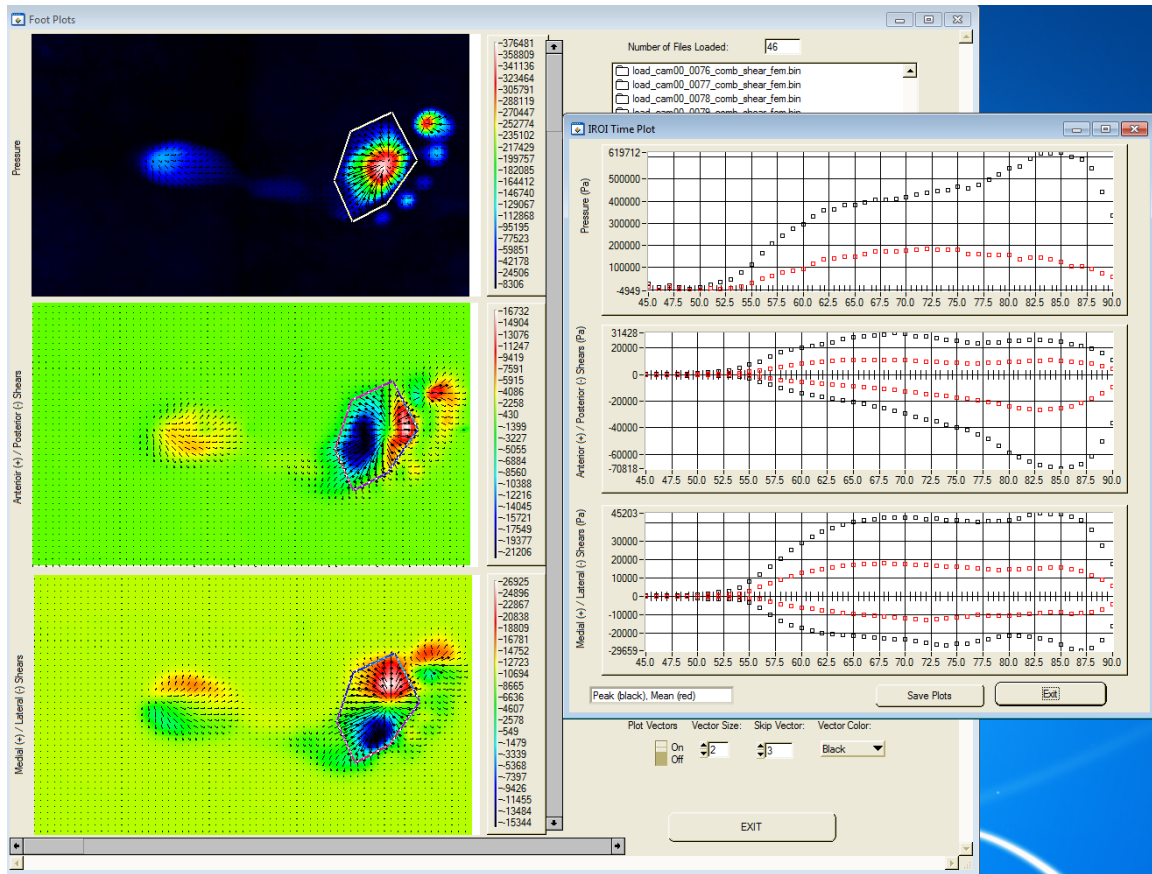




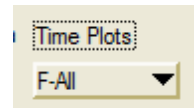
The final time plot is an **IROI** which is user selected by activating the **IROI** pulldown time plot. Then move the graphic cursor to the pressure display; this cursor is indicated by the cross-hair/arrow-head combination. Move to the first point of interest and right or left click the mouse (do not hold down the button); move to the next point of interest and right or left click the mouse; and proceed until an enclosure back to the original point has been made. The **IROI** should be displayed along with the graphical results. As with the **ROI**, the **IROI** shows both the mean and peak values. Data can be saved as an ascii excel file. As with the **ROI**, The saved data includes an ascii excel file that provides the coordinates of the **IROI**. To erase the **IROI** from the graphics displays, the user should hit the plot button.



If the user is right clicking the mouse and the program is not drawing the IROI, then it is likely that the graphics cursor is not located in the pressure display.

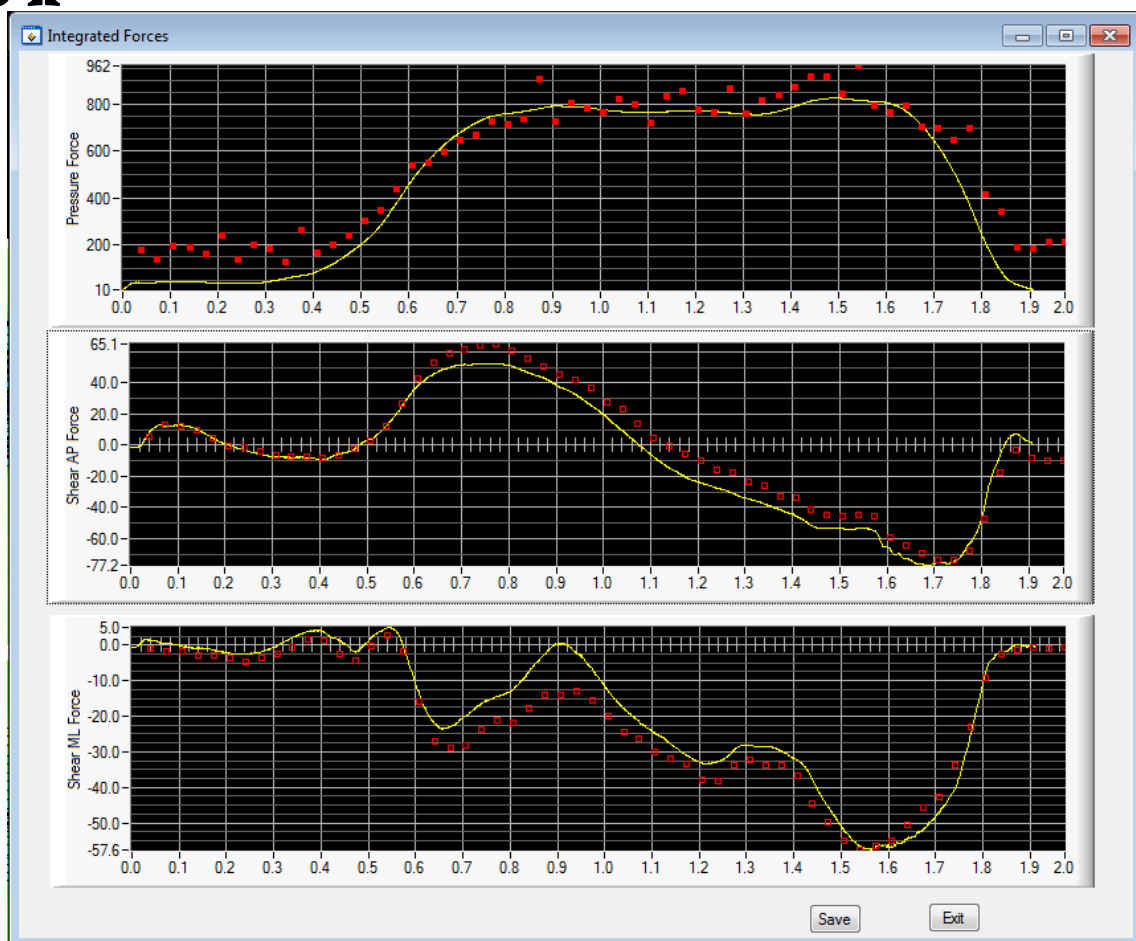


The next series of time plots is the integrated force time plots that are used to compare the integrated forces of the S3F image sensor to those of the force plate. There are two options for force plots F-All and F-ROI. F-All calculates the integrated forces over all of the foot sensor's field of view. The user selects this from the Time Plots pull down and the program then asks what thresholds are to be applied.



The thresholds affect both the pressure and shear plots. Once the thresholds are entered, then a comparison plot is displayed to the user. The solid yellow line in this figure corresponds to the force plate results while the red squares corresponds to the integrated forces of the S3F image sensor (in units of Newtons).

This image shows the 'IntegrationThresholds' dialog box. It contains two input fields: 'Pressure Threshold' set to 10000.00 and 'Shear Threshold' set to 1000.00. There is a 'Continue' button at the bottom.



Force Plate Results (yellow line) with S3F Image Sensor Integrated Forces (red-squares)

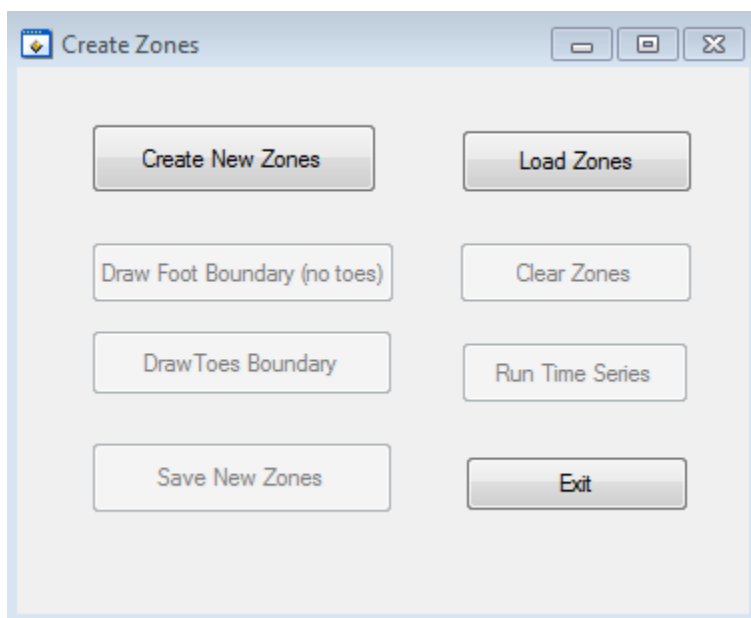
The F-ROI function works much the same as the F-ALL except the user must select a region of interest over which the force integration occurs. The user must still enter a threshold for the pressure and shear data. The comparison plot is then displayed with the force plate and image sensor data. To save this data the user must select the SAVE button on the comparison plot which allows the data to be stored in an ascii text format which can be read with Excel or any other text readers.

9. Establishing Zones and Zonal Analysis

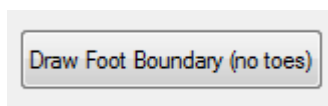
Zones refer to the 10 zones/areas established by Cavanagh, et al. (1987) for studying foot dynamics. Since zones are established relative to the pressure display, it is important that all parts of the foot step be visible in the pressure image. To accomplish this, before starting the zone creation procedure, the user should do the following:

- 1) Select the **Composites** button (see Section 4), and create the composite images (if not created already). Next, select the **Composite-Sum** and hit the **Plot** button to update the displays along with the max's and min's.
- 2) Turn off the vector plots by turning the **Plot Vectors** toggle to **Off** (see Section 6).
- 3) Turn the **Scale Pressure Plot** toggle to **On**; and while leaving the max value as is, enter a value of -100000 for the pressure min. Then hit the **Plot** button to update the display with the new pressure scale.
- 4) Re-adjust the max and min scale if all parts of the pressure image are not clearly visible.

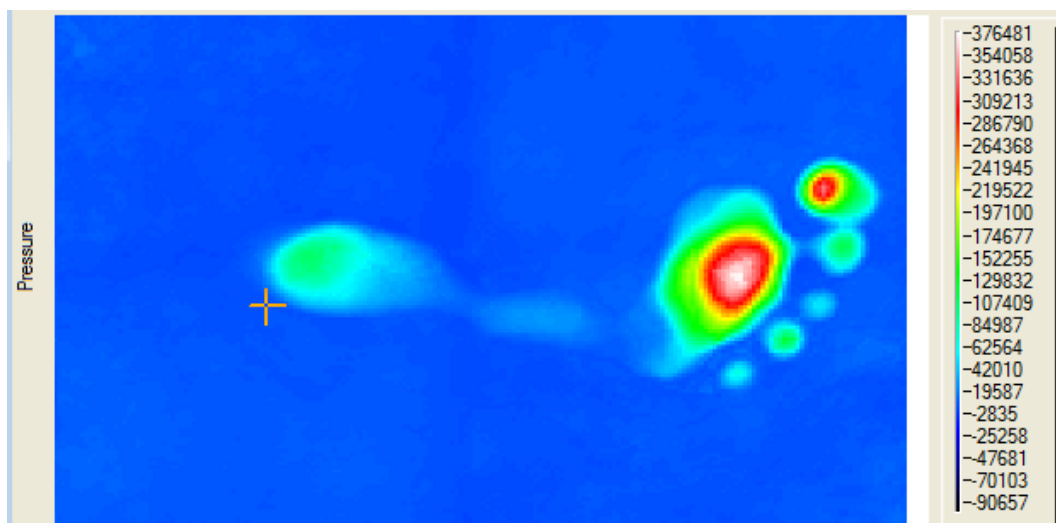
To start the zone analysis, select the **Zones** button. The Create Zones dialog will appear, giving the user the option to create zones or load previously created zones.



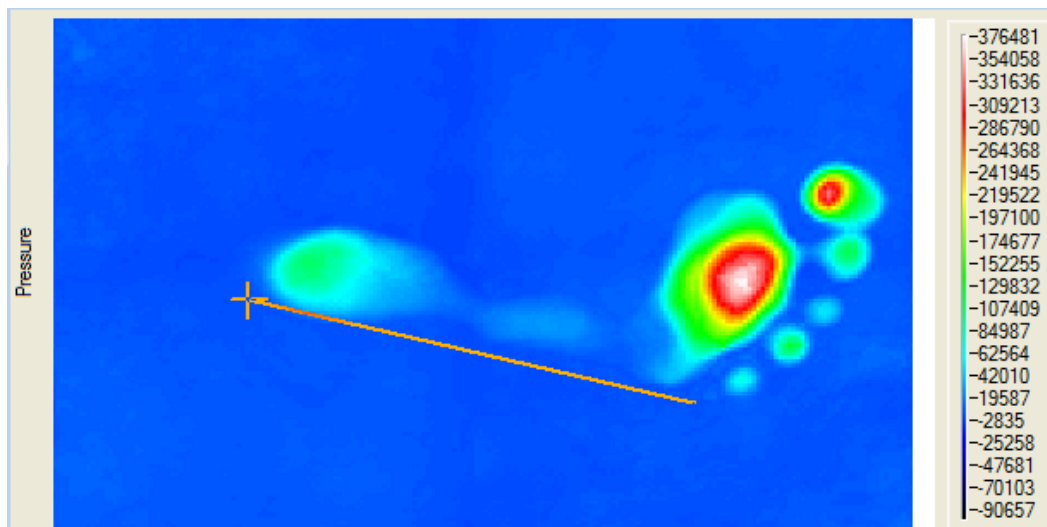
To start the graphic creation of zones, the user should select the **Create New Zones** button, and the **Draw Foot Boundary** button will become active. Select the **Draw Foot Boundary** button and place the graphic cursor (the combined cross-hair/arrow-head) at the beginning of the lateral heel of the pressure image as shown in the sequence of images below. Right-click the mouse (once and release), and proceed to the



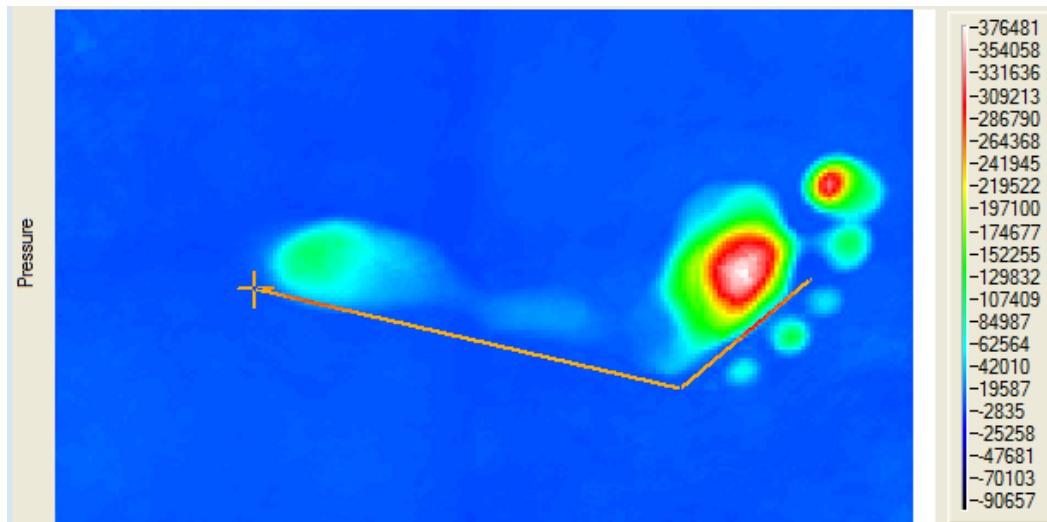
next point that is located at the region just below the lateral metatarsals. Right-click the mouse for the second point, and a line will be drawn between the first and second points. Next move the cursor to the region between the 2nd and 3rd toes and right-click the mouse. An additional line segment will be displayed. Move the cursor to the point above the medial 1st metatarsal, and right-click the mouse. Another line segment will be added as a result. Move the cursor to a point above the medial heel region, and right-click the mouse (another line segment will be added). Finally move the cursor to the starting point, and right-click which should result in the completion of a coffin-shaped enclosure around the foot minus the toes. Once the outer region is complete, the program will subdivide the foot into six zones.



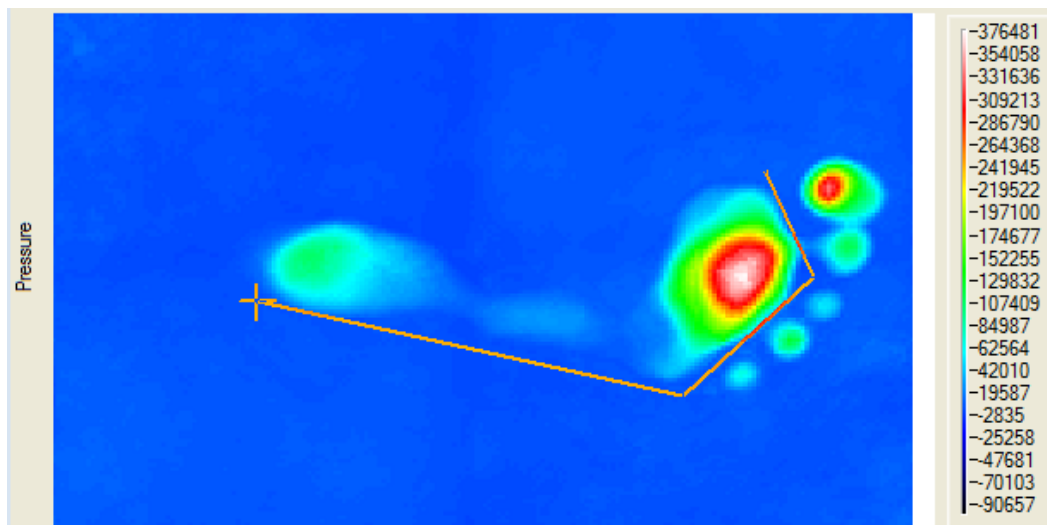
First Point in Draw Foot Boundaries – Lateral Heel.



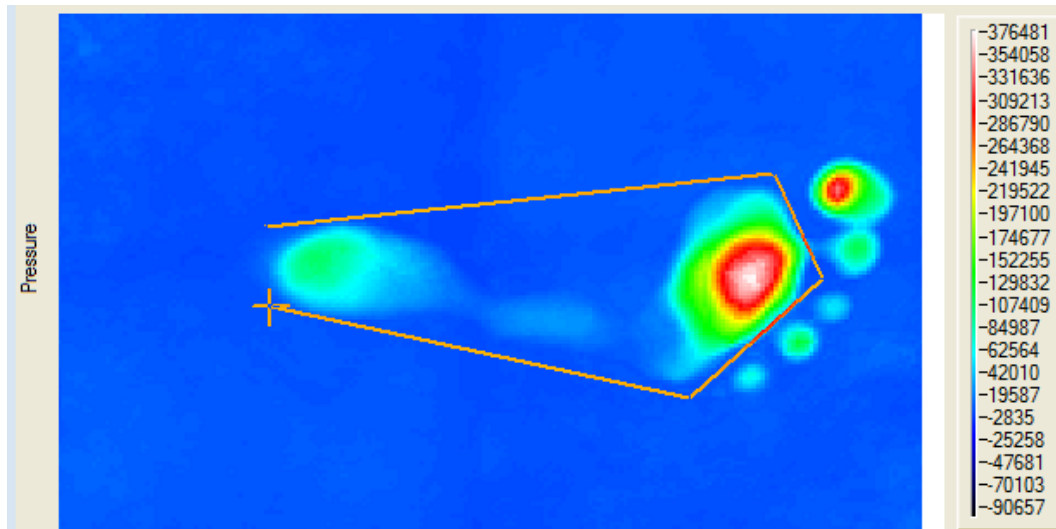
Second Point in Draw Foot Boundary – Lateral Metatarsals.



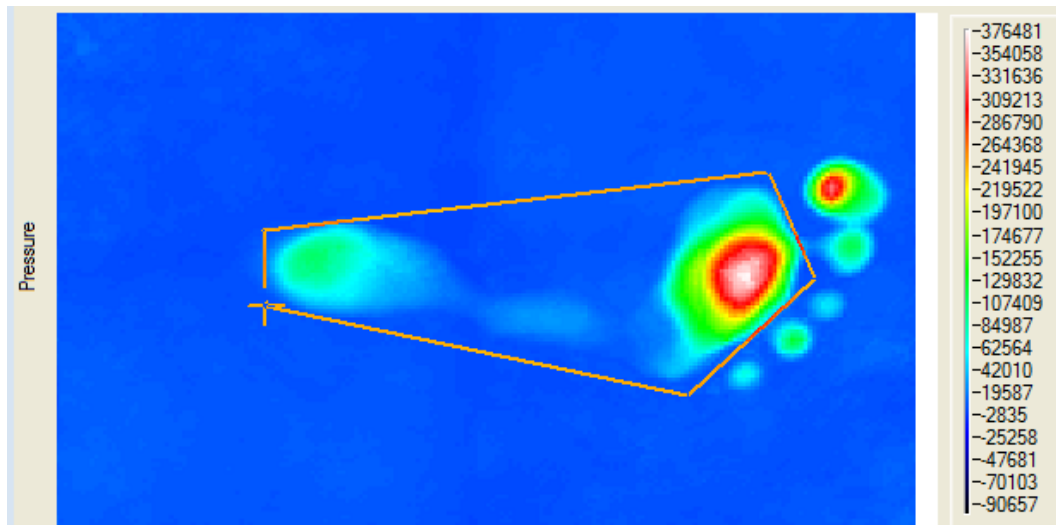
Third Point in Draw Foot Boundary – Between 2nd - 3rd Toes.



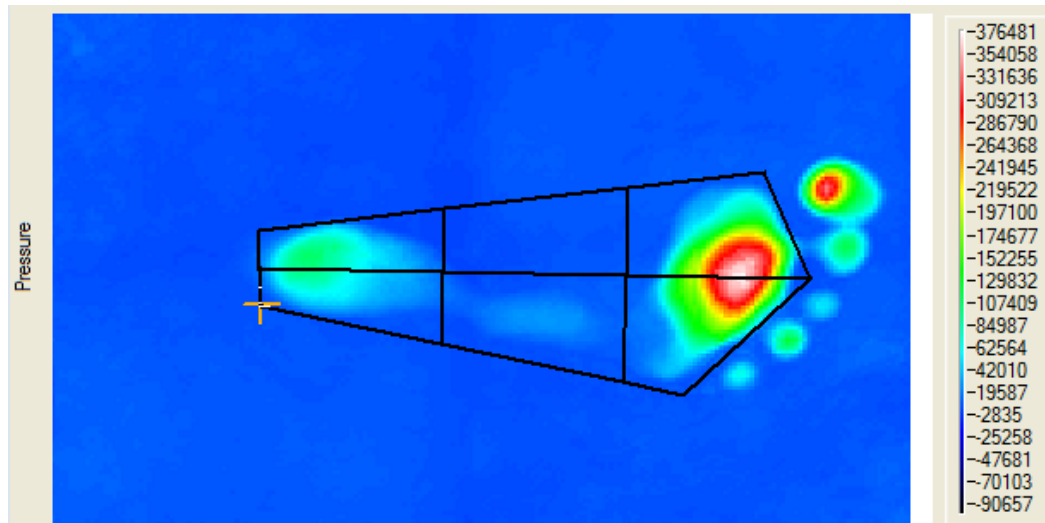
Fourth Point in Draw Foot Boundary – Medial 1st Metatarsal.



Fifth Point in Draw Foot Boundary – Medial Heel.

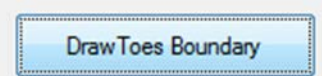


Sixth Point in Draw Foot Boundary – Lateral Heel.



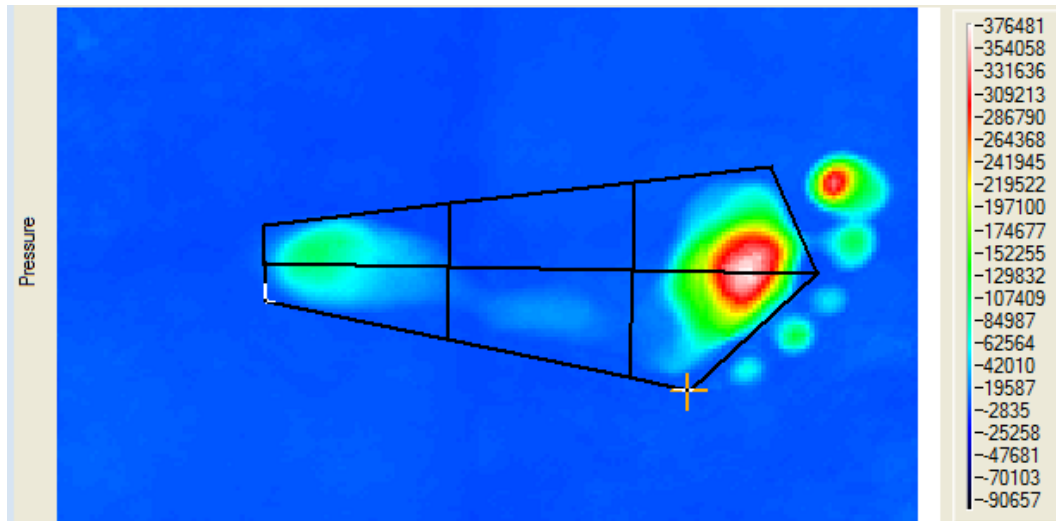
Boundaries of Draw Foot after Draw Foot Boundaries Procedure.

Next, the **Draw Toes Boundary** will become active. To proceed, select this button and draw the toes boundaries. This is a multi-step process that is similar to the draw foot body boundary except that it concerns the toes. A total of eight line segments will be drawn between the following points:

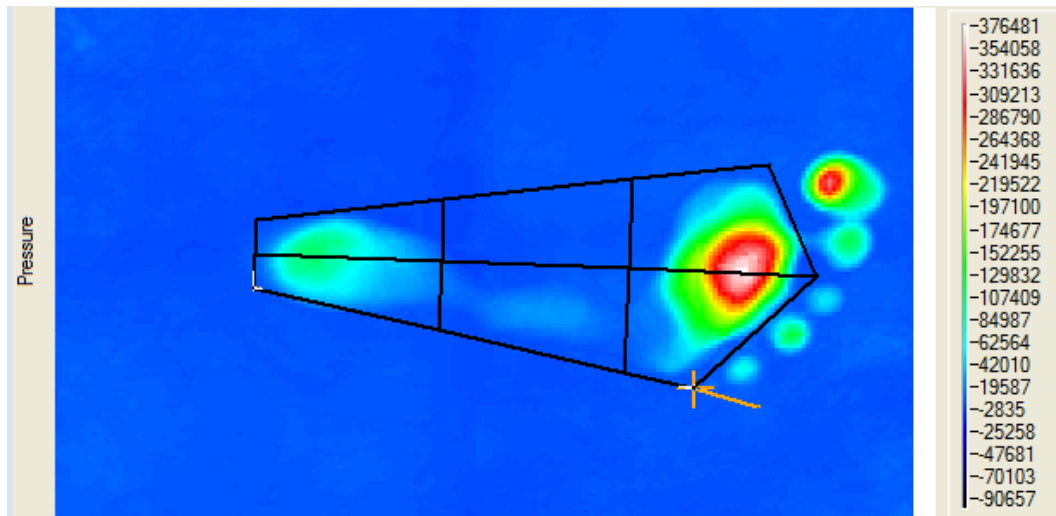


- 1) the first starting from below the lateral metatarsal and proceeding,
- 2) to the outer small toe
- 3) to the region between the 2nd and 3rd toes
- 4) to the region between the hallux and the 2nd toe
- 5) to the medial region above the hallux
- 6) to the outer medial region of the 1st metatarsal
- 7) to the region between the hallux and the 2nd toe
- 8) to the region between the 2nd and 3rd toes, and finally
- 9) to the starting region below the lateral small toe

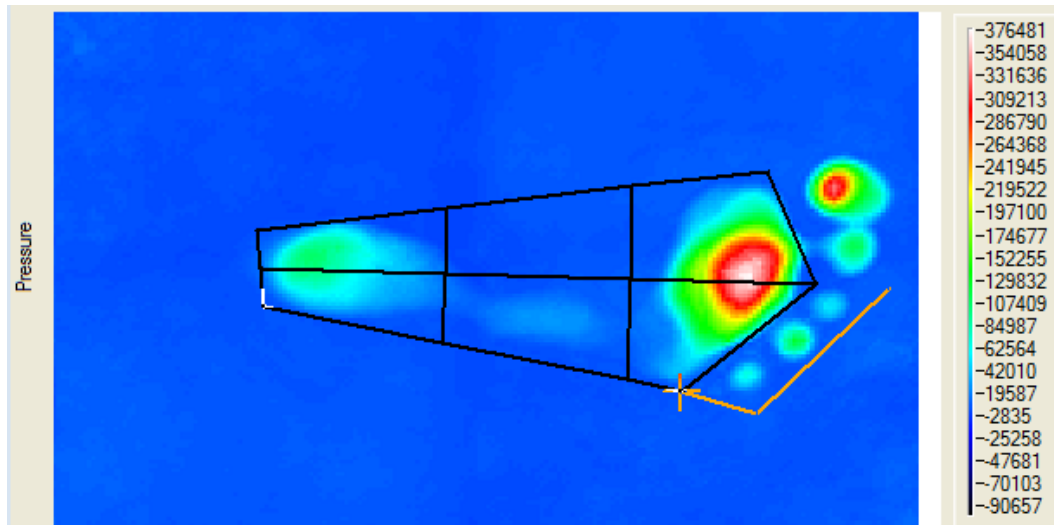
As with the foot boundary, each segment is determined by moving the cursor to the correct region and right-clicking the mouse. When determination of the toe boundaries is complete, the program will display all ten zones.



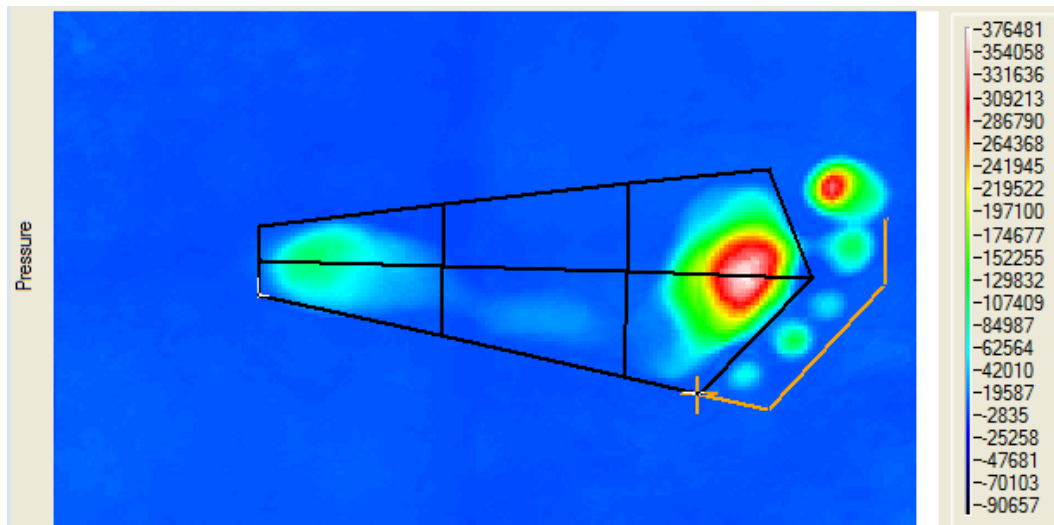
Starting Point of Draw Toe Boundaries – Below Lateral Metatarsals.



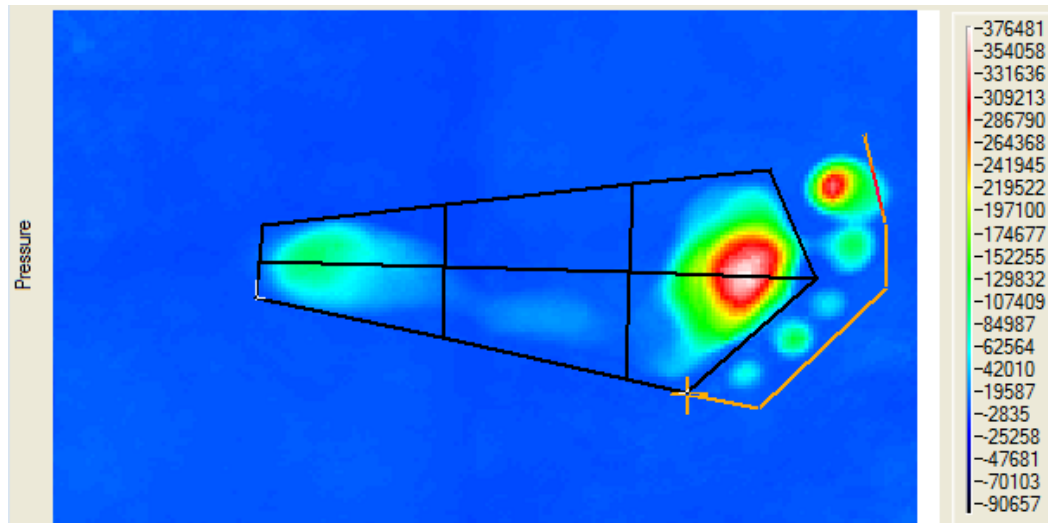
Second Point of Draw Toe Boundaries – Outer Lateral Small Toe.



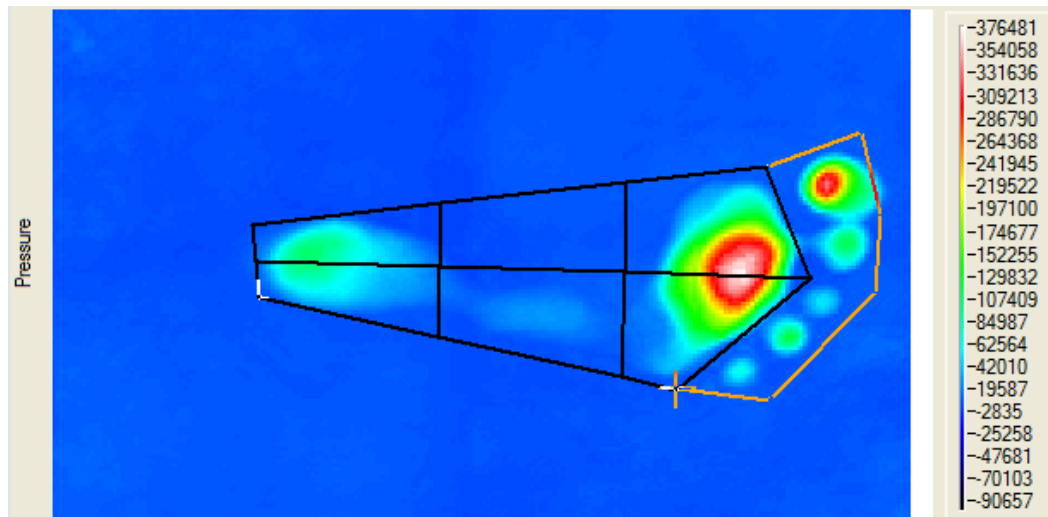
Third Point of Draw Toe Boundaries – Between 2nd and 3rd Toes.



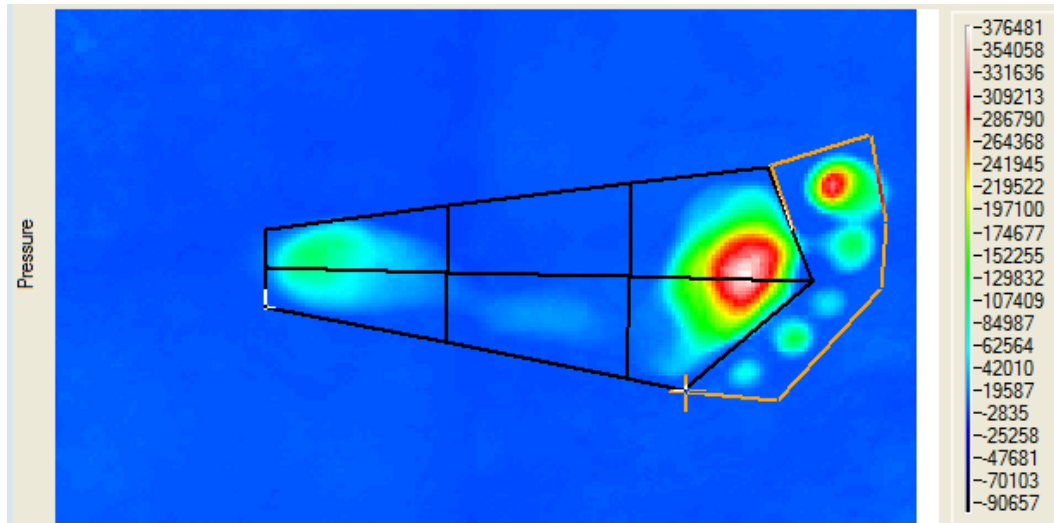
Fourth Point of Draw Toe Boundaries – Between Hallux and 2nd Toe.



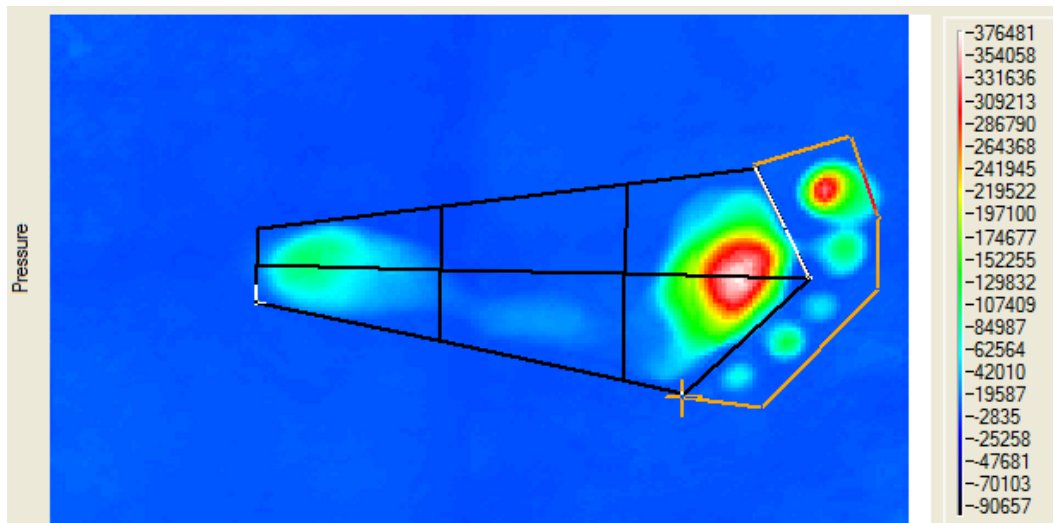
Fifth Point of Draw Toe Boundaries – Above Medial Hallux.



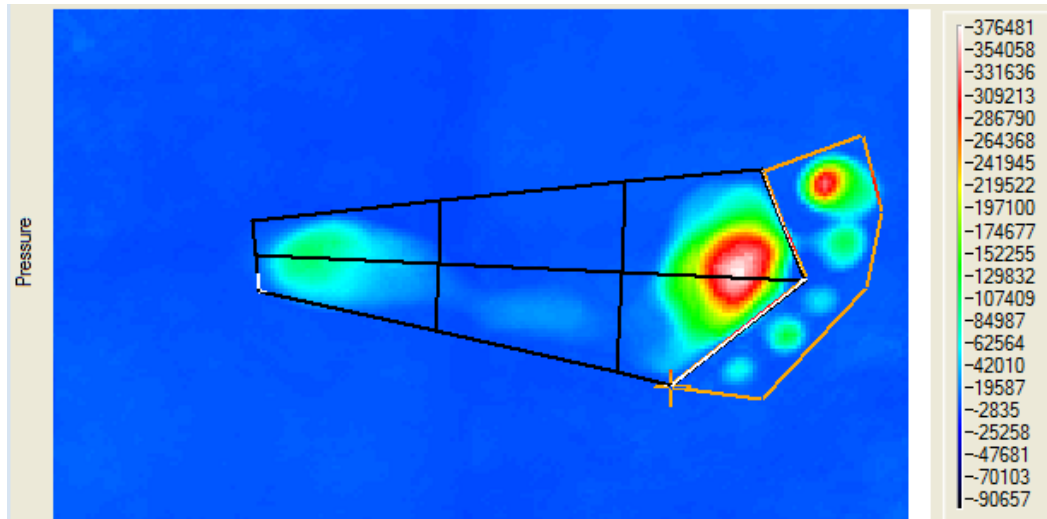
Sixth Point of Draw Toe Boundaries – Outer Medial Region of 1st Metatarsal.



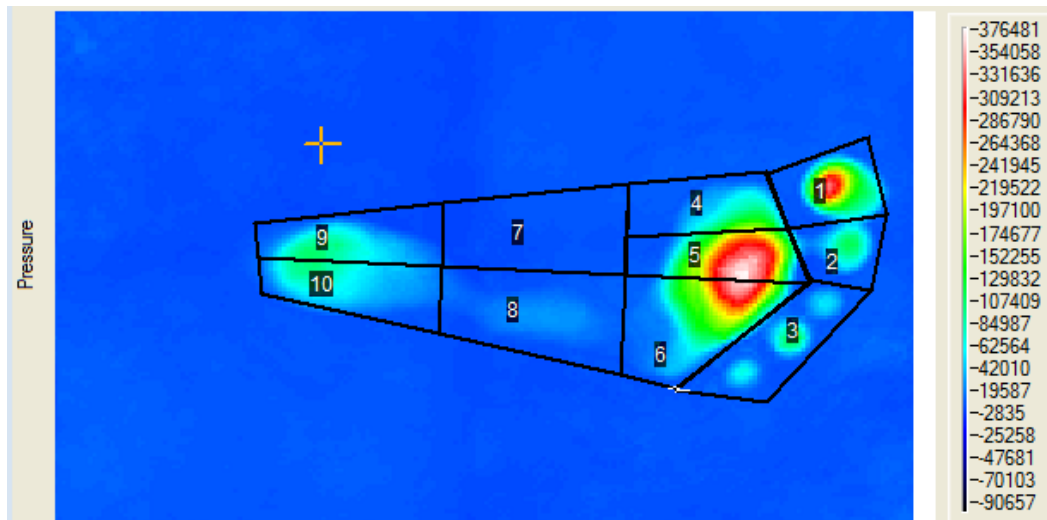
Seventh Point of Draw Toe Boundaries – Between Hallux and 2nd Toe.



Eighth Point of Draw Toe Boundaries – Between 2nd and 3rd Toes.

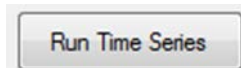
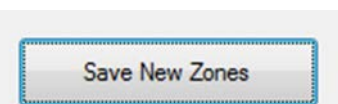


Ninth and Final Point of Draw Toe Boundaries – Starting Point at Lateral Small Toe.



Zones Identified After Foot and Toes Boundary Procedure.

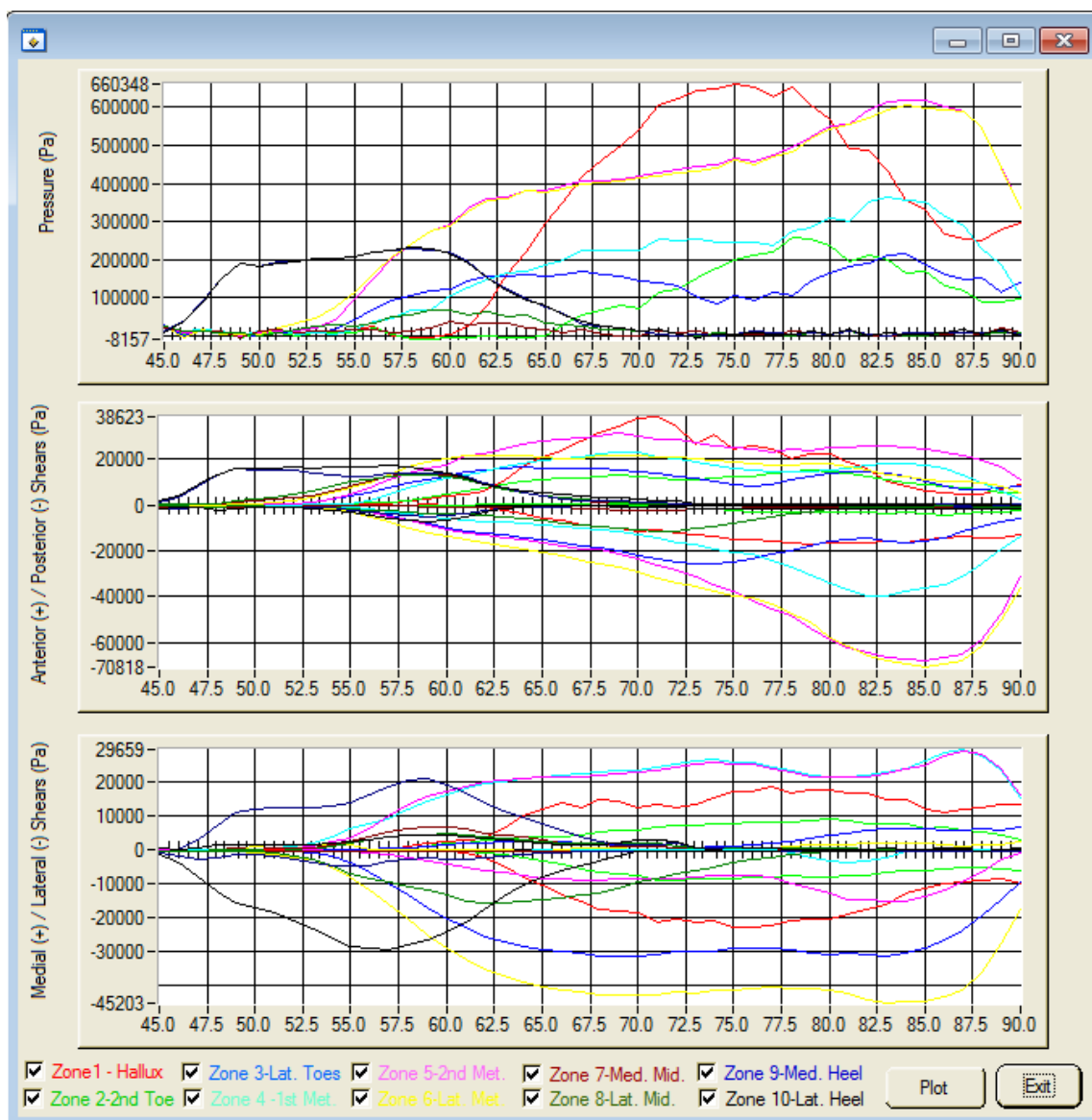
The **Save New Zones** button will become active, and the user can save the regions. Once the zones have been saved, the **Run Time Series** button will become active, and a time plot for each zone will be generated. This is illustrated below where all zones are initially plotted on a single graph. Note that the time plot information is automatically saved as an ascii excel file with the save zone name. For example, if the save zone name was Zones, the running of a time series will automatically create two files named Zones_graph.csv and Zones_graph_coords.csv that contain the time data for each zone and



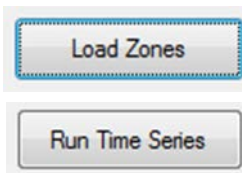
the boundary coordinates, respectively. The data in these files are ascii comma separate value (*.csv) files that can be read with any text reader or with the Excel program.

Note that the individual zone plots can be turned on or off by selecting the appropriate toggle box that is located at the bottom of the graph and hitting the **Plot** button to refresh the graphs. When finished inspecting the graphs, the user should hit the **Exit** button to clear the graph and the **Clear Zones** button and the **Exit** button to exit the zone procedure.

Clear Zones

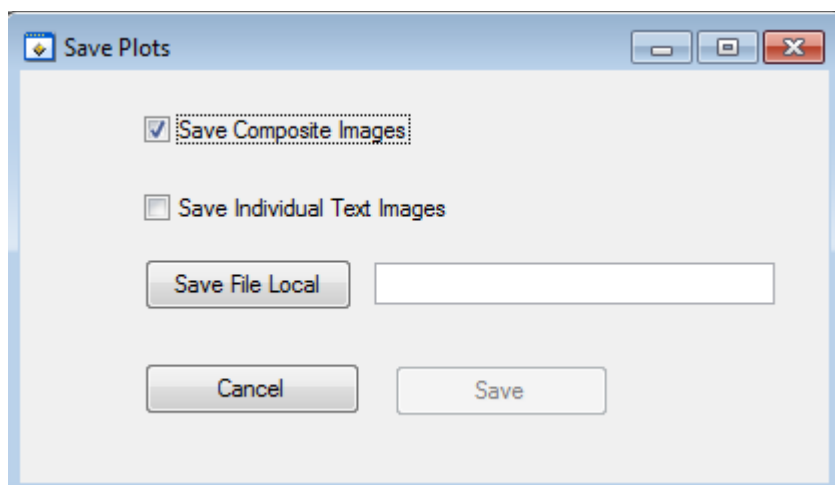
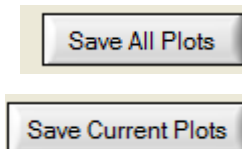


Any previously saved zone can be loaded by selecting the **Load Zones** button and navigating to the directory containing the zones. The zone info will be loaded and shown on the FootPlots display. A Time Series can then be run by selecting the **Run Time Series** button.



10. Saving Displays and Plots

The pressure and shear displays of the FootPlots program can be saved either as Tiff files that can be combined to produce movies, or as text files for export to programs for further analysis. This is accomplished by selecting either the **Save All Plots** button or the **Save Current Plots** button. In the Save All Plots case, all of the loaded images will be saved by FootPlots to a user-selected directory. Activating this button causes the **Save Plots** dialog to be displayed to the user. The user should decide which plots to save -- either the composite images (pressure, anterior/posterior shear, and medial/lateral shear) or individual text plots of the pressure, anterior/posterior shear, and medial/lateral shear. The composite images will be Tiff files that mirror those displayed by the FootPlots program, including vectors if vectoring plotting is selected, while the text images will be three individual files for each frame of data in an ascii format. Both outputs can be read with the ImageJ program and used for further analysis. The user should activate the **Save File Local** to inform the program where to save the images and the **Save** button to save them. The program will then display each frame, beginning with the first, and save a copy of it to the desired location.



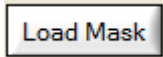
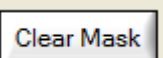
If the **Save Current Plots** is selected, then, the same **Save Plots** dialog is displayed to the user; however, only the currently displayed frame will be saved.

Note that both **Save Plot** procedures utilize the current Plot Vector and Scale Plot vector plot settings to display and save the data. If the user wishes to change these settings so that all the images are on a common scale, this must be done before hitting the **Save** button.

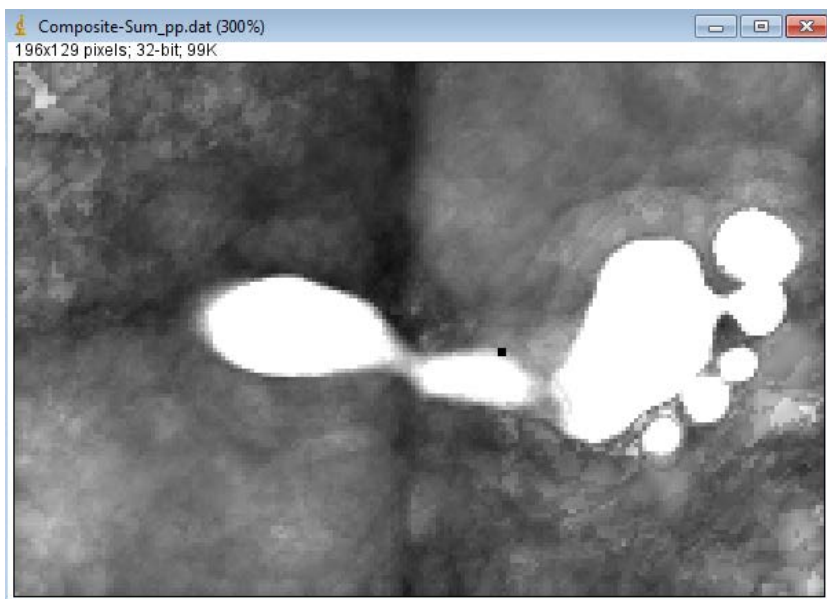
To create an AVI movie film from the Composite Images saved by the FootPlots **Save All Plots** function, the following procedure should be followed:

- 1) Start the ImageJ program.
- 2) Load the saved composite tiff images - File>Import>Image Sequence.
- 3) Save the image sequence to an AVI movie file - File>Save As>AVI.
- 4) Exit ImageJ

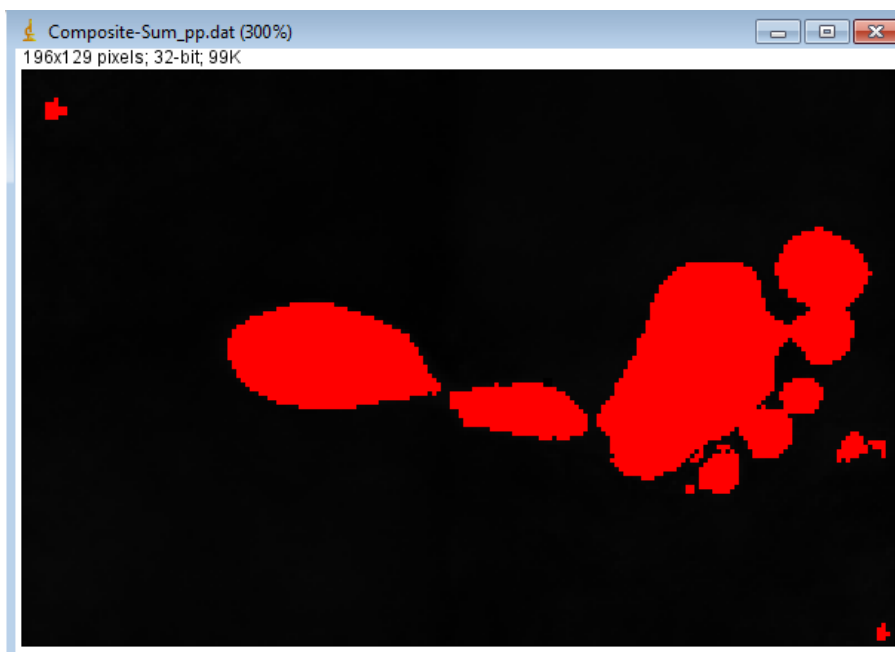
11. Loading Masks and Clearing Masks

The Load Mask function allows the user to load a text image created in ImageJ as a mask for masking of the foot image. To load the mask, hit the **Load**  **Mask** button and select the text mask image to load. The user should hit the **Plot** button to update the current displays, and the masked foot display will  be shown. To clear the mask, select the **Clear Mask** button, and the mask will be erased. The ImageJ procedure to create a text mask image is as follows:

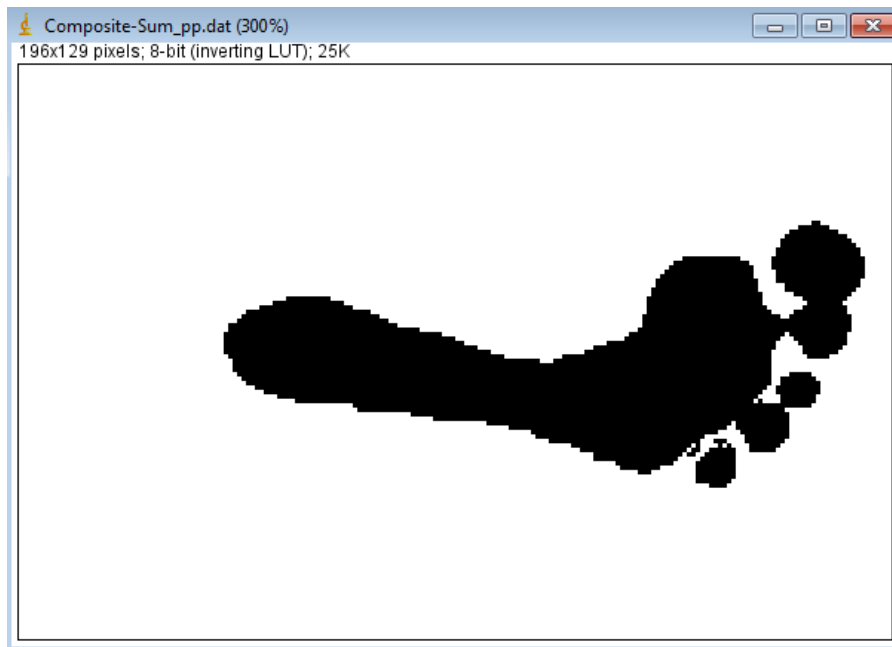
- 1) In the FootPlots program create the **Composite** images. Select either the Composite-Sum or the Composite-Peak image and hit the **Plot** button to ensure that this is the currently selected image. Select the **Save Current Plots** function and have the program save the individual text images. Note that all three pressure and shear images will be saved; however, for masking only the pressure image will be used.
- 2) Start the ImageJ program and using File>Import>Text Image, locate the pressure image just saved by the FootPlots program and load it. An example is shown in the image sequence below. Now in ImageJ select Image>Adjust>Threshold and adjust the threshold so that the foot is the primary image. Hit the Apply button in the threshold dialog and convert the image to one in which all pixels below the threshold are zero and all pixels above the threshold are 255. Next, using the Color Picker tool and the Paintbrush tool, fill in any missing areas for the foot or cover up any noise areas outside the foot. Finally, using the File>Save As>Text Image, save the mask image.



Pressure Composite-Sum Image Saved as Text Image and Displayed in ImageJ.

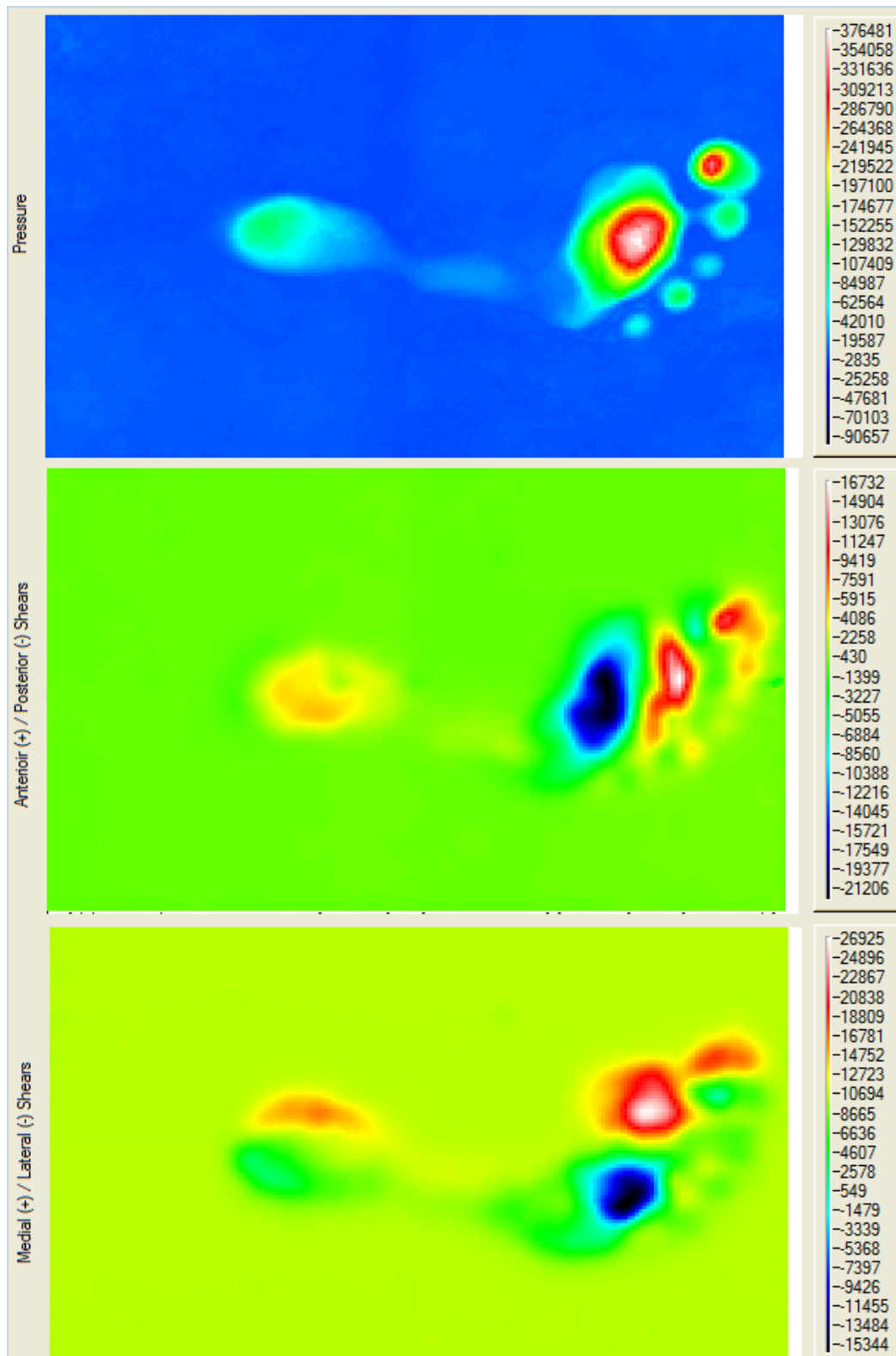


Pressure Image after Applying Threshold.

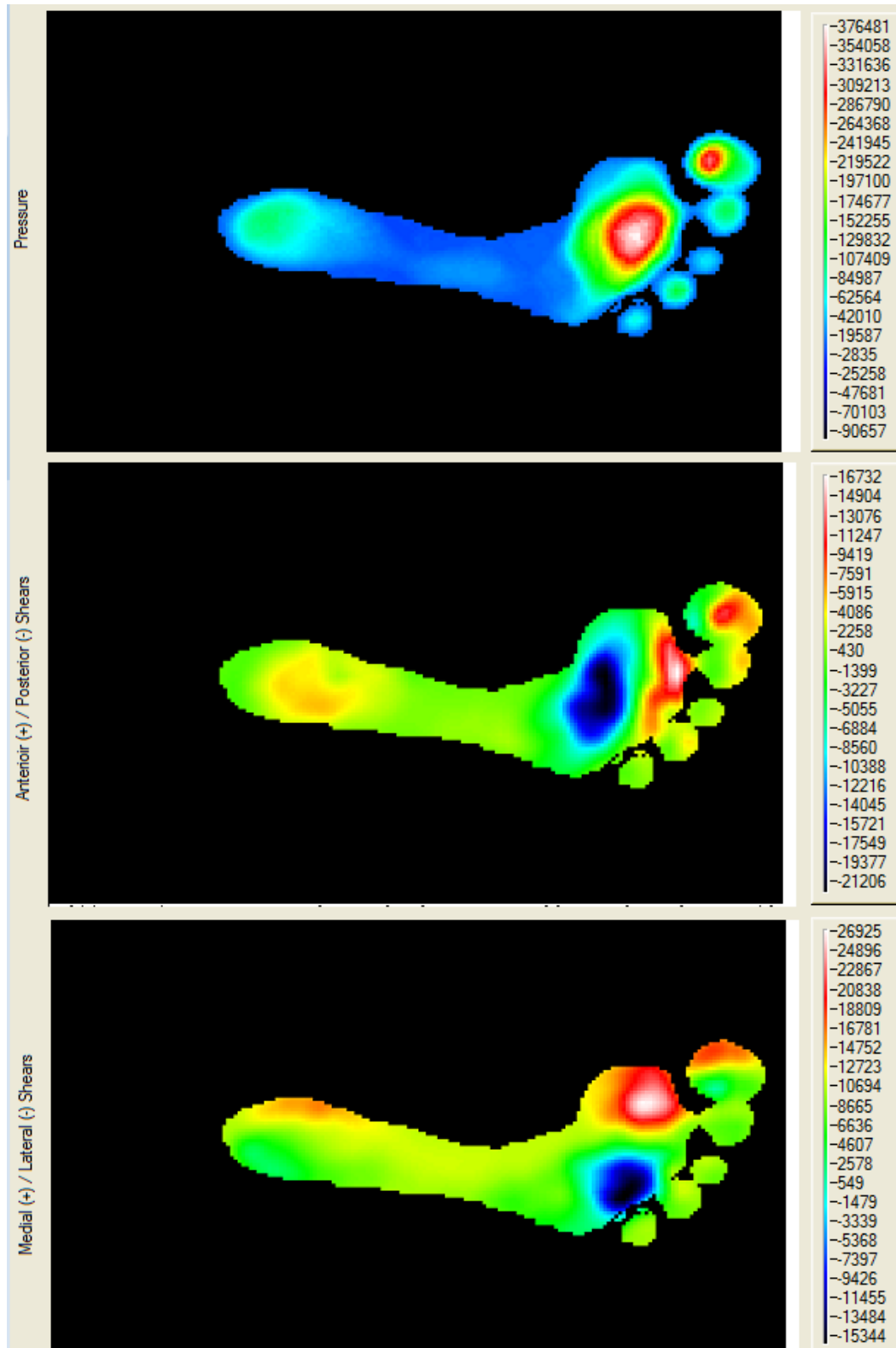


Pressure Image after Using Color Picker and PaintBrust to Eliminate Noise and Fill in Missing Regions.

- 3) Once created the mask can be loaded into the FootPlots program and used to mask off areas where no data is present. An example is shown below.



Composite-Sum Image for a Foot Step.



Composite-Sum Image for a Foot Step after Loading Mask Image.

References

Cavanagh PR, Rodgers MM, liboshi A. (1987), Pressure distribution under symptom-free feet during barefoot standing, *Foot and Ankle*, Apr., Vol. 7, No. 5, pp. 262-276.

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