Structural Health Monitoring

# Acquisition and Processing of Motion Tape Field Data

M. Makila, T. Pierce, Y-A. Lin, and K. Loh

**Abstract—**A lack of efficiency and the potential for musculoskeletal harm when engaging in physically demanding activities is a major health concern. Today, technology can measure muscle conditions and movements, but cannot do both on a wide scale of activities. Nanocomposite fabric sensors, known as motion tape, can measure the stress and skin strain from the body's surface as it moves. To monitor the health of those using motion tape, it is crucial to efficiently extract and process data gathered from the field. This study's objective is to create a system capable of processing motion tape data from the field, analyzing it to make signals forming the strain interpretable, and exporting it for even further analysis. The first stage of the approach was to develop a script that could read all locally stored data from a microSD. The data was then processed to make it plottable, converted into impedance, and then normalized to produce an accurate depiction of the strain. The script was written with the functionality to compare multiple data samples at once, compute Fourier transforms to isolate signals in the strain, and even export them in pieces to be locally saved for the user.

## I.INTRODUCTION

Physical movement is crucial to daily life and spans from simply walking to more strenuous tasks. While engaging in physical activity, there is always a risk of musculoskeletal injury from the tension placed upon the body. In particular, those who engage in physically taxing activities, such as athletes and members of the armed forces, will have a much higher risk of injury due to the intensity their professions demand. To prevent injuries, several sensors have been developed to monitor the human body's vitals.

One such sensing apparatus created is known as Motion Tape, characterized as a graphene nanocomposite film combined with commercially-developed kinesthetic tape via spray-coating [1]. Motion Tape is flexible and piezoresistive, meaning that its resistance changes as it bends. It functions through its application to the surface of an individual's skin as it bends. Hence, while the individual moves, this wearable sensor will non-invasively capture muscle movements and skin strain. Motion Tape's flexibility, piezoresistance, and ability to capture muscle engagements, mark it as a powerful tool to map the body's movements and detect skin strain.

An important aspect of monitoring health is to ensure the gathered data is extracted efficiently and made interpretable so that it is useful. To acquire field test data from the Motion Tape, a microcontroller known as the MSP430 collects the changes in resistance due to movement at a rate of 90 samples per second. Via a voltage divider circuit on a custom printed circuit board (PCB), this resistance is converted to a raw voltage value that can be stored onto a microSD card by the MSP430 microcontroller.

Once the data has been acquired by the microcontroller, a script was made to begin processing it. Several other wearable device systems process their data manually file-by-file on MATLAB but do not include an automated script to process it with several plotting options [3]. Due to a high sampling rate, there were gaps left in the data's timestamps to gather data quickly. These gaps had to be filled utilizing the script, and then the raw voltage gathered had to be analyzed and converted into impedance to yield useful information on the strain. The data was then normalized to make it even more interpretable.

## II.METHODOLOGY

### *A. Extracting Field Data*

To begin processing samples taken with the Motion Tape, a script was produced to extract field data from a microSD supplied by the MSP430 microcontroller. The first part of the process required MATLAB's file input features. The script was written to recognize and extract any files matching the proper comma-separated value (CSV) file extension. Every CSV file was then displayed to the user of the script, allowing them to select different files for processing. After ensuring files could be read from the foreign microSD, a menu was created for user readability. A menu ensured a user could select different processing schemes for the files they chose.

After extracting the files from the microSD and adding a framework for usability, the next step was to finalize the incomplete data collected from the MSP430 microcontroller. There were "gaps" left between each second of the data's timestamps to maintain the sampling rate of 90 samples per second, making it initially unusable. In the script, these spaces between the timestamps were filled by breaking each second of data into its corresponding milliseconds and adding a new timestamp design with milliseconds included. By filling these spaces with new timestamps, the timestamps and raw voltage values had a one-to-one correspondence and could thus be plotted, as shown in Figure 2. The raw voltage was retrieved from a voltage divider on a custom-built printed circuit board (PCB), as depicted in Figure 1.

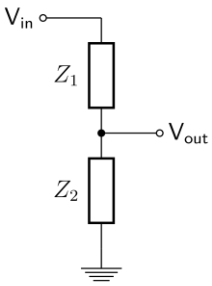



Fig. 1. The voltage divider circuit utilized to convert resistance values from Motion Tape into voltage.

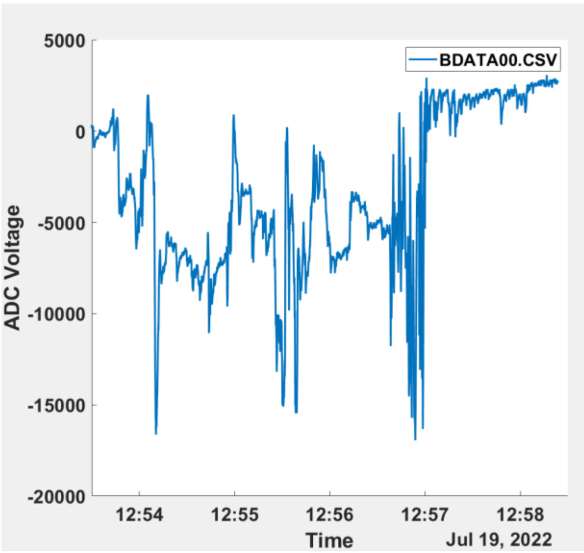
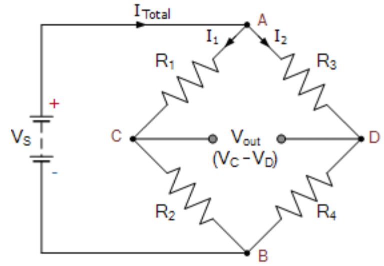



Fig. 2. A graphical display of the raw voltage collected from the voltage divider circuit plotted against the time.

### B. Graphical Strain Data using Impedance

Even with the data plottable, it had no significant meaning without being further analyzed. The next part of the script dealt with converting the raw voltage data into impedance values. Impedance refers to the opposition to electric flow and is measured in Ohms. The relationship between the Motion Tape system's components, raw output voltage, and impedance was correlated via the Wheatstone Bridge [2]. A model of the Wheatstone Bridge is shown in Figure 3, where the supplied voltage was three volts, the impedance was represented by the first resistor, the second resistor was represented by a potentiometer value, the output voltage was imported from the data file, and resistors three and four were the same, reducing their formulaic expression to one-half. The equation was rearranged to solve for the impedance and written as a function in the script to eventually plot impedance versus time. The data extracted from the microSD was the output voltage, and that value was used to calculate the impedance. A portion of the script included a function written to calculate the output impedance in the circuit for each voltage sample in the data. With the data now plotted as impedance versus time, a depiction of the strain emerges in Figure 4. This image of the strain was useful for understanding the movement of the body's muscles via the surface of the skin.




$$V_{out} = V_s \left( \frac{R_2}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right)$$

Fig. 3. The Wheatstone Bridge circuit diagram and its corresponding equation, relating every component of the circuit together.

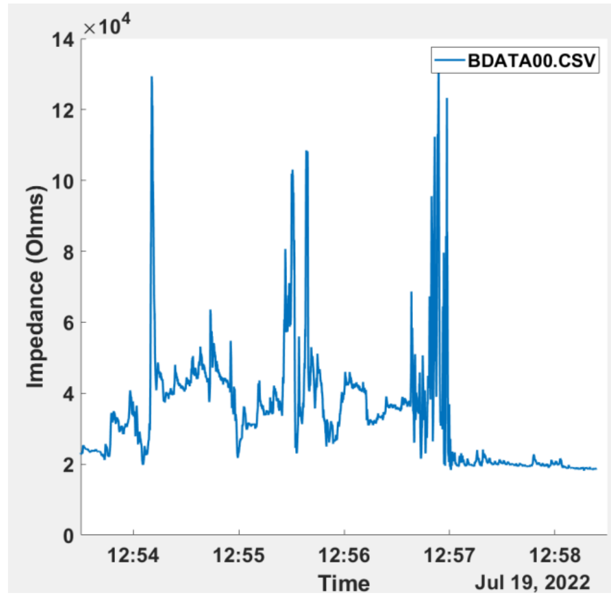



Fig. 4. A graphical representation of strain shown as impedance plotted against the time.

To make the strain more interpretable, it was necessary to normalize the impedance values. This required finding the nominal value of the dataset, which was found by writing a function to extract the first two seconds of data, which was largely unnecessary as the sensors were first calibrated in that timeframe. This nominal value was an average of those first two seconds of data. Every impedance value was divided by the nominal value to scale it to make the data easier to perform calculations with and remove redundancies, as shown in Figure 5. By normalizing the data, it was possible to measure the proportional change in impedance. This allowed all samples to be compared, no matter how differently sized their values were initially.

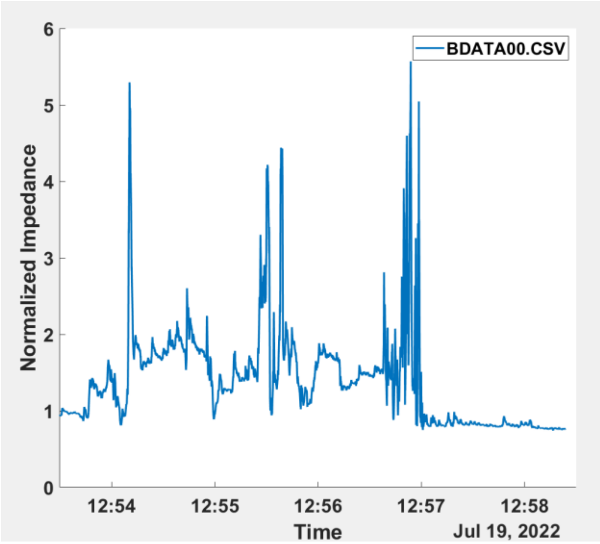



Fig. 5. Normalized Impedance is plotted against time on a smaller proportional scale.

### C. Signal Isolation using a Fast Fourier Transform

An additional feature of the script included a plotting scheme in which the power spectral density (PSD) of the dataset could be calculated and plotted against frequency. This utilized MATLAB's built-in Fast Fourier Transform (FFT) algorithm. The FFT was calculated using the normalized impedance. The normalized impedance was first zero-mean averaged by averaging all of the normalized impedance data values and subtracting this average from each data point. The data resulting from the FFT algorithm was divided by the length of the dataset and broken into two halves to prepare for plotting. This graph of the PSD against frequency allowed for the isolation of varying signals that comprised the strain and the filtration of noise from data. Signals like breathing and heart rate that contributed to strain were derived from the plot.

## III.RESULTS

The most important outcome of this study was the ability to take complex field data and easily examine it the same day. Data processing became largely automated and rapid as a result of the written script. The script's functionality also allowed for the strain to be measured and plotted against a commercial device's data from field tests, as shown in Figure 6. These field tests were conducted using Motion Tape paired with the MSP430 microcontroller to save data. Several trials were performed and as movement occurred, the commercial device and Motion Tape recorded data. This data was compared and plotted via a new version of the script to compare outside commercial data against data supplied from the Motion Tape's system.

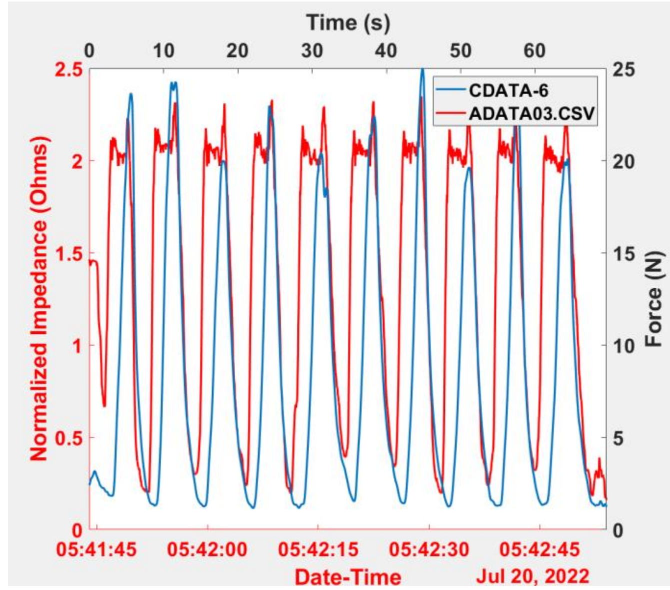



Fig. 6. A plot of one trial between the force collected from a commercial device in Newtons (blue) and the Motion Tape system's data as strain (red).

Processed data was also able to be exported through the script's data-saving feature. In the script, processed data tables were saved and as per the user's choice, saved in intervals or as a whole into an excel spreadsheet. This allowed users to easily select only the portions of the data files (which varied from several seconds to several hours), they were interested in examining for further analysis.

## IV.CONCLUSIONS

This paper presents a novel system capable of extracting and processing the data collected during field tests for Motion Tape. Altogether, the development of the script made the analysis more efficient and allowed for plotting strain easily. With an interpretable strain plot, field data can now track the muscle engagements of an individual while they exercise. The scripts were utilized to compare data gathered from a commercial device with data gathered from the Motion Tape's system. Allowing for data exportation facilitates even more analysis on specific sections of the Motion Tape trials.

## V.ACKNOWLEDGMENTS

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## VI.REFERENCES

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