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Correlation between EMG, Thermal Imaging and Ultrasound for the Muscle Strength Measurement of Biceps Brachii

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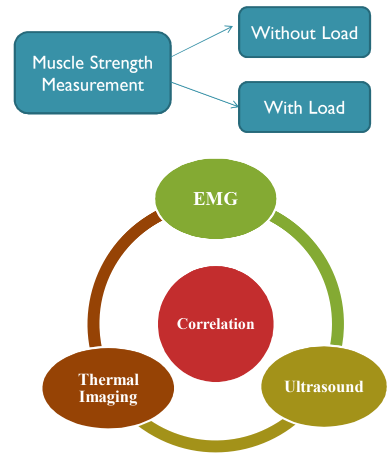
Introduction



Overview

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Problem Statement

- Signal occurs during contraction where there are **synchronous activities in the muscles**.
- This **signal can be obtained** by EMG, US and TI.
- Research on correlation between any of these three modalities **were limited**.
- A mechanism is needed for the signal acquisition when we **combine all the 3 terms** for muscle strength measurement.

Objectives

- To **understand the basic concepts** of EMG, ultrasound and thermal imaging for the muscle activity signal acquisition.
- To **investigate the correlation** of EMG, ultrasound and thermal imaging for the muscle condition.
- To **introduce a new system** that integrates these modalities.

Critical Analysis

Ref.	Author	Anatomical Part	Machine Specifications	Parameters	Merits	Demerits
[1]	H. Li, G. Zhao, Y. Zhou, X. Chen, Z. Ji, L. Wang. (2014)	- Tibialis anterior (TA) muscle on the hemiphegia patients.	•Linear array ultrasound transducer •EMG surface electrodes	• Muscle strength level (MSL) • RMS • Muscle thickness change (TC)	• The rectified thickness change (TC) amplitude and mean of EMG signals showed a linear correlation. • The sonomyography (SMG) is more preferable for estimating the MSL as compared to EMG.	• Further investigation should be performed to a large number of subject in order to obtain an accurate data results. • Factors such as age, gender and malignant origins need to be considered for future experiments.
[2]	N. Nejat, P.A. Mathieu, M. Bertrand. (2012)	-Right biceps brachii muscle	•Surface electrodes •Load (1kg) •Strain gauge unit •Physiodata amplifier •High density linear probe	• EMG signals • Average RMS of EMG signal • Contraction force • MVC	• The biceps brachii muscle structure is best to be used to control the myoelectric protheses. • US imaging convinced that how the muscle cross section variate in various positions that can indicate the changes in EMG signals.	• Future investigation is required to determine how an individual's compartment could be activated voluntarily.
[3]	J. Y. Guo, Y. P. Zheng, Q. H. Huang, X. Chen. (2008)	-Extensor carpi radialis muscle.	• US transducer • EMG electrodes • US Pulser / Receiver • Electronic goniometer	• A-mode US images • Joint angels • sEMG signals • Muscle thickness change • sEMG RMS	• The deformation of muscle and the sEMG root mean square signals were linearly correalated with the angles of wrist extension.	• A study need to be done on the other body joints or on the disabled subjects. • It was difficult to place both the 1D sonomyography and sEMG sensors (electrodes) as the muscle area was small.

Critical Analysis *(Cont.)*

Ref.	Author	Anatomical Part	Machine Specifications	Parameters	Merits	Demerits
[4]	Q. H. Huang, Y. P. Zheng, X. Chen, J. F. He, J. Shi (2007)	- Forearm muscles (Wrist motion)	• Ultrsound probe • EMG electrodes • Metronome • Goniometer	• sEMG signals • Joint angle signals. • Force • Velocity • Ultrasound B-scan images • sEMG RMS	• The amount of ultrasound gel does not significantly affects the sEMG signals. • Correlation between the sEMG signals , ultrasound images and joint angels signal showed a good performance and a better outcome.	• The sampling rate need to be increased. • Uniform calibration procedure is necessary to ascent the other similar system measurements. • Further studies need to be done on large number of subjects and the experiment need to be performed on the dynamic contractions as well.
[5]	J. Petrofsky, M. Laymon. (2005)	•Biceps •Bracheoradialis •Quadriceps •Gastrocnemius muscle	• 2 bipolar vinyl foam adhesive EMG electrodes (Ag-AgCl) • 4-channel EMG amplifier • Isometric stain gauge transducer bar	• Isometric contractions • Average frequency • Amplitude • RMS voltage • Conduction velocity	• The EMG amplitude signal and tension for isometric contractions showed a linear relationship. • The fatigue of muscle can only be indicated when the amplitude of EMG signal is increased, and the skin temperature ia high as well.	• Muscle temperature may variate due to some aspects. • It was difficult to identify the fatigue before warming the muscle to the normal(basic) temperature.
[6]	Y.Tsutsui, T.Tanaka, S.Kaneko, M..Q. Feng. (2005)	-Quadriceps femoris -Biceps femoris (knee joint)	• Ultrasound transducer • Torque sensor • A/D converter	• Force • Angle • Torque	• Implemented a new non-invasive sensor (UMS) for the muscle activities and it is able to enhance the precision of torque measurements.	• The fluctuation effected by disconnecting the transducer from skin need to be suppressed as it displease the torque measurement.
[7]	C. Simon, P. VanBaren , E. S. Ebbini. (1998)	Tissue	• Therapeutic U/S unit • Transducer • Thermocouple sensor • Ultramark 9 imaging system • Hydrophone	• Temperature change • Echo stretching / compression	• The experimental outcome showed a good relationship between the echo location shifts and the increment in temperature. • Better accuracy is achieved when any immateriality is heated by the HIFU therapeutic beam.	• The HIFU is not widely endorsed in medical clinics. • The effects of the thermo-acoustic lens caused ripples by the gradients in temperature distribution.

Methodology

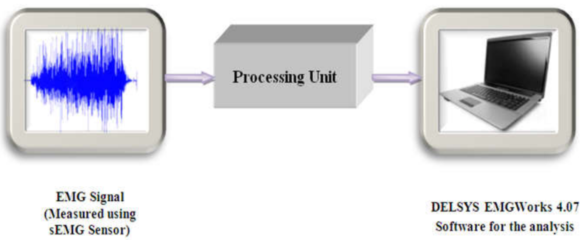
- Conducted the experiment on 8 male students with strong biceps muscles.

EMG
- Equipment: 16 Channel Trigno Wireless EMG Set (DELSYS)
- Software: EMGWorks Software 4.07
- Parameters: Amplitude Analysis MAV RMS

Thermal Imaging
- Equipment: Fluke Ti32 9HzThermal Imager
- Software: Fluke SmartView 3.1 Software
- Parameter: Temperature (˚F)

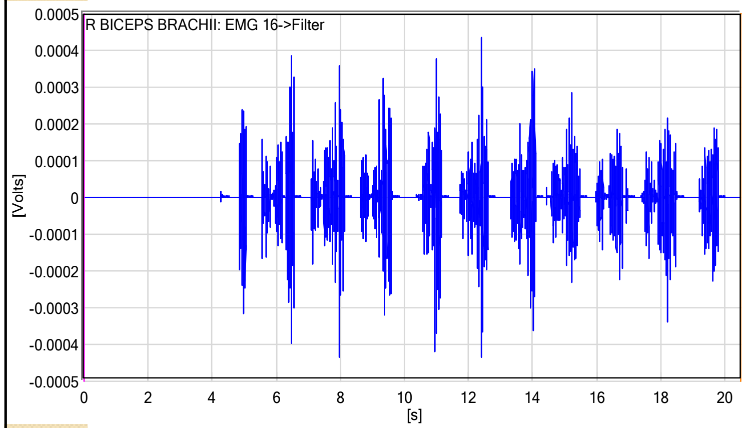
Ultrasound
- Equipment: Ultrasound Machine GE Logiq E BT 2011
- Software: MATLAB
- Parameter: Muscle Compression

EMG

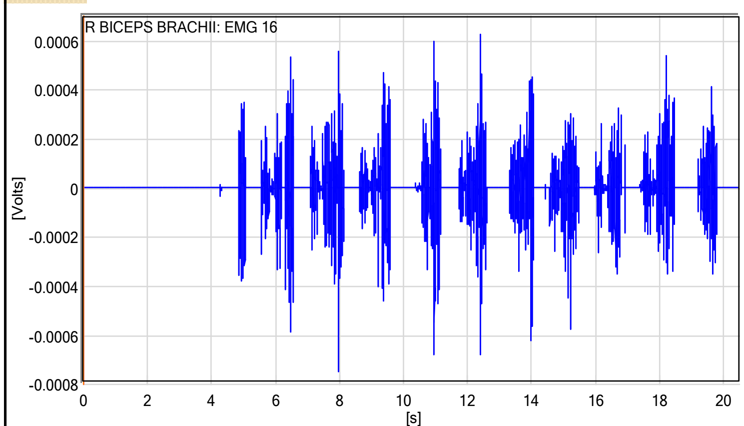


Overview on sEMG signal

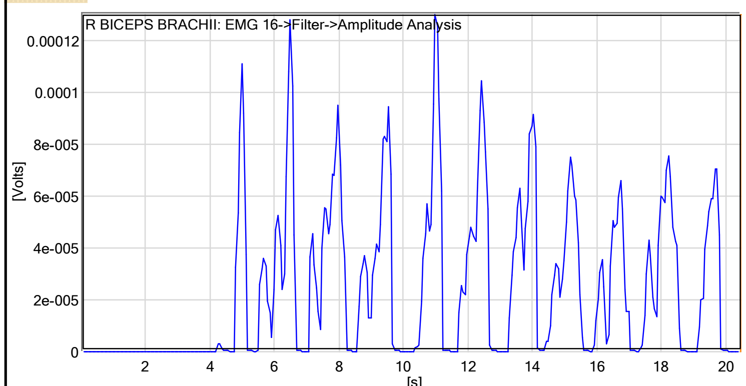
Filtration using Chebyshev filter and Band-pass response



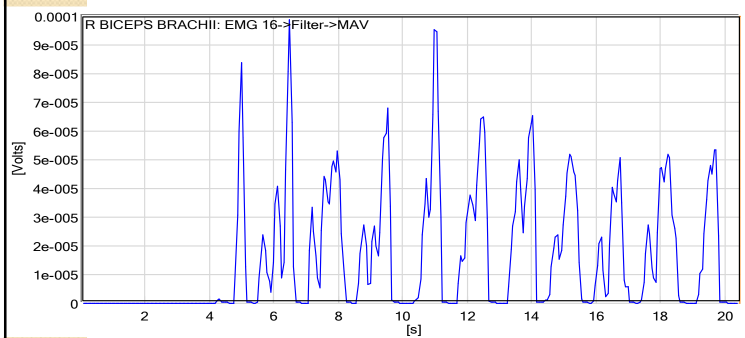
Raw sEMG signal



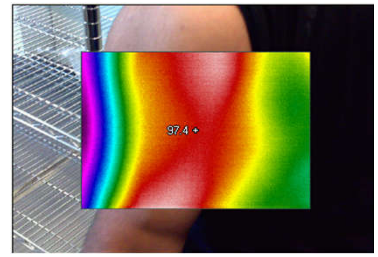
Amplitude Analysis signal



Mean Absolute Value (MAV) signal

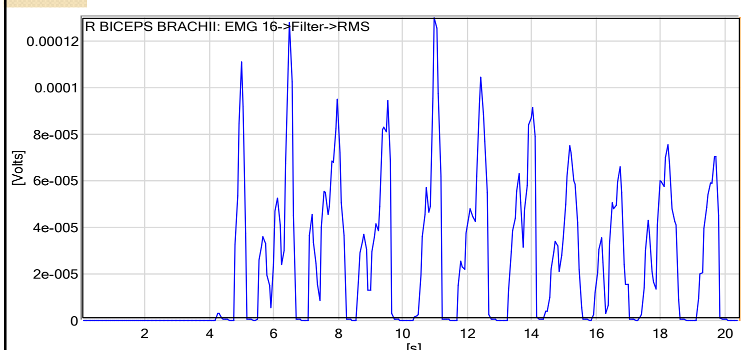


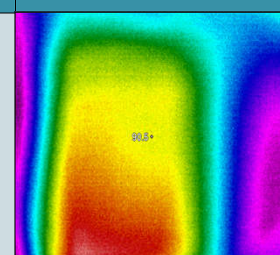
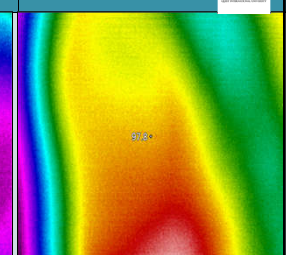
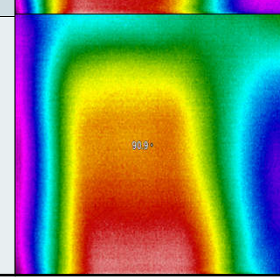
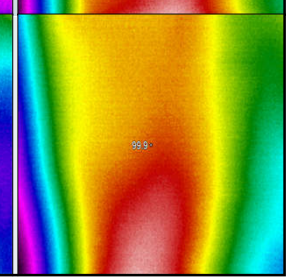
Thermal Imaging



Thermal Image Acquisition on the Right Biceps Brachii Muscle

Root Mean Square (RMS) signal



Subject	Contraction	Without Load	With Load
2	Before		
	After		

Ultrasound

QIU

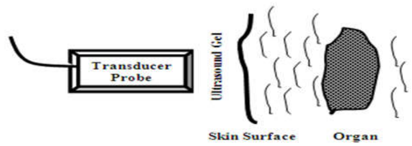
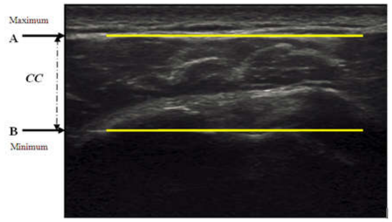


Image of the estimation on how the ultrasound image is acquired



Profile of Contraction Change (CC) of the Biceps Brachii Muscle

$$CC = AB_{max} - AB_{min}$$

Per unit

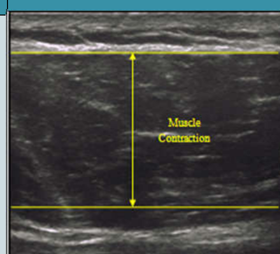
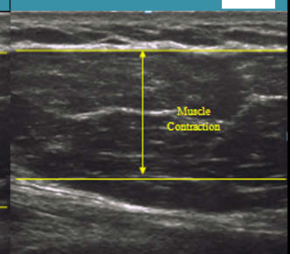
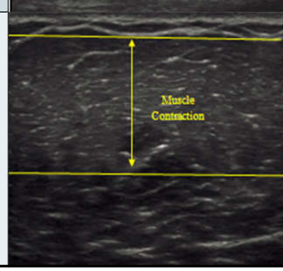
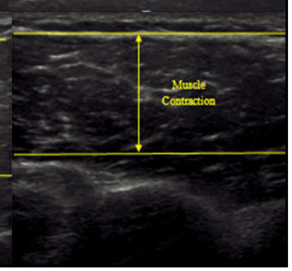
QIU

- The Per Unit value is used to quantify the parameters and is a method of expressing quantities (parameters) as a **proportion of pre-defined base quantities.**
- Generally, the PU is the **ratio of the original value to its base value** which will then results in a **dimensionless** or no unit values.
- Base value in this case study is the measurement's highest value for each parameter that has been proposed.

$$\text{Per Unit} = \frac{\text{Present Value}}{\text{Base Value}}$$

- The **analysis can be simplified** by using the PU system and therefore **the relative magnitude** of all similar quantities **can be directly compared**.

QIU

Subject	Contraction	Without Load	With Load
2	Before		
	After		

QIU

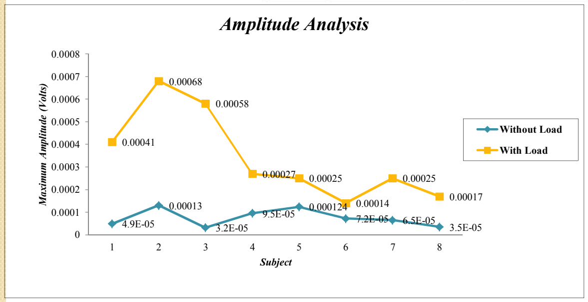
ANALYSIS RESULTS

EMG

QIU

Comparison of EMG Amplitude Analysis (AA) for Without Load and With Load performance

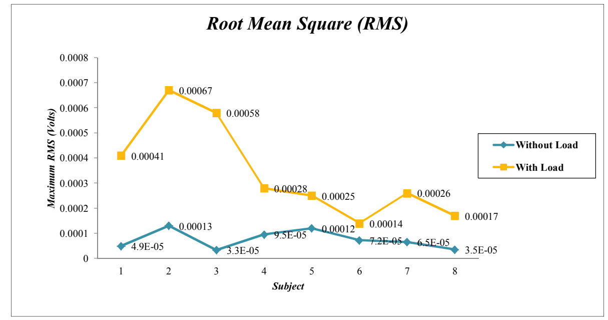
Subject	Maximum Amplitude (Volts)	
	Without Load	With Load
1	0.000049	0.00041
2	0.00013	0.00068
3	0.000032	0.00058
4	0.000095	0.00027
5	0.000124	0.00025
6	0.000072	0.00014
7	0.000065	0.00025
8	0.000035	0.00017



QIU

Comparison of Root Mean Square (RMS) for Without Load and With Load performance

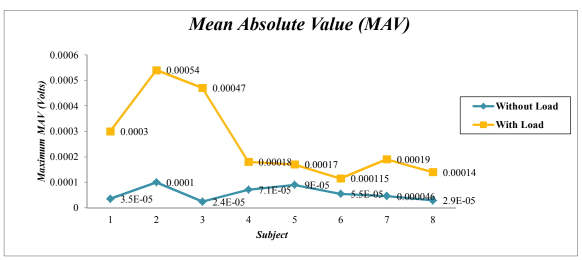
Subject	Maximum RMS(Volts)	
	Without Load	With Load
1	0.000049	0.00041
2	0.00013	0.00067
3	0.000033	0.00058
4	0.000095	0.00028
5	0.00012	0.00025
6	0.000072	0.00014
7	0.000065	0.00026
8	0.000035	0.00017



QIU

Comparison of Mean Absolute Value (MAV) for Without Load and With Load performance

Subject	Maximum MAV (Volts)	
	Without Load	With Load
1	0.000035	0.0003
2	0.0001	0.00054
3	0.000024	0.00047
4	0.000071	0.00018
5	0.00009	0.00017
6	0.000055	0.000115
7	0.000046	0.00019
8	0.000029	0.00014



QIU

- The **increase of amplitude** in the signal of with load condition is consistent for all the subjects.
- That means all eight subjects **achieved higher amplitude** after the muscle contraction **using load**.
- It reveals the **relationship between the muscle contractibility, *Mc* and the amplitude** where the function is given by:

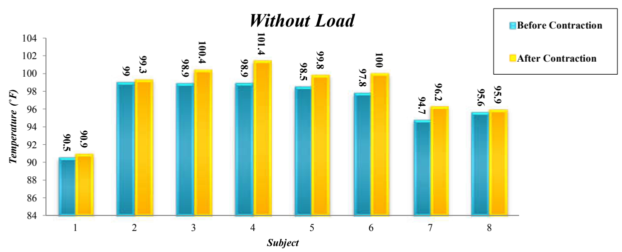
$$Mc = f(E_A)$$

- The equation demonstrates that the **muscle contractibility is proportional to the amplitude** of the EMG.
- The result of **MAV and RMS** also shows the increase in amplitude when the subject performs contraction using load of 10lb dumbbell.

Thermal Imaging

Temperature Measurement (Without Load)

Subject	Temperature (°F)	
	Before	*After*
1	90.5	90.9
2	99	99.3
3	98.9	100.4
4	98.9	101.4
5	98.5	99.8
6	97.8	100
7	94.7	96.2
8	95.6	95.9



- The results of the thermal imaging showed a **good relationship** between the muscle contractibility, ***Mc* and the temperature change** of the both without load and with load performance.

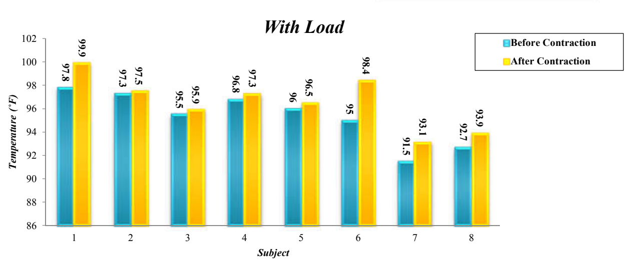
$$Mc = f(T_l)$$

- The function above shows that the **increase in temperature after the contraction activity** is **proportional** to the muscle contractibility, *Mc*.
- The higher the value of the subjects' **temperature**, the **muscle contraction increases**.

Thermal Imaging

Temperature Measurement (With Load)

Subject	Temperature (°F)	
	Before	*After*
1	97.8	99.9
2	97.3	97.5
3	95.5	95.9
4	96.8	97.3
5	96	96.5
6	95	98.4
7	91.5	93.1
8	92.7	93.9



Ultrasound

Subject	Compression Length (cm)					
	Without Load			With Load		
	Before	After	Contraction Change, CC	Before	After	Contraction Change, CC
1	4	2	2	2.8	1.8	1
2	4	3.5	1.5	3.5	3	0.5
3	4.2	3	1.2	3.5	2.5	1
4	4	1.5	2.5	2.5	2	2
5	3.5	2.5	1	2.8	2.3	0.5
6	3.5	2.5	1	2.5	2	0.5
7	4.1	3.5	0.6	2	1.5	0.5
8	3.5	2.5	1	1.8	1	0.8

Difference between the Muscle Thickness for the Without Load and With Load Conditions

- The results demonstrated that the Contraction Change **(CC) of without load** condition is **higher** than the CC of **with load** condition.
- It means that the **compression of muscle using load is higher** as compared to the muscle compression without using load.
- The **biceps brachii were compressed more** when the subject was applying too much of pressure on the muscle area.
- This shows a **proportional relationship** between the **muscle thickness and the muscle contractibility** which is given by the equation below:

$$Mc = f\left(\frac{1}{h}\right)$$

- Where ***h* is the contraction change (CC)** of the muscle that reveals the contraction change of the with load activity is higher than the contraction change of the without load activity.

Correlation between EMG and Ultrasound (US)

Subject	Without Load		
	EMG	Ultrasound	
	Amplitude Analysis	Thickness Change	Muscle Compression
1	0.0721	0.8	Low
2	0.1912	0.6	Low
3	0.0471	0.48	Low
4	0.1397	1	Low
5	0.1824	0.4	Low
6	0.1059	0.4	Low
7	0.0956	0.24	Low
8	0.0515	0.24	Low

Per Unit Values for the EMG and US (Without Load)

Subject	With Load		
	EMG	Ultrasound	
	Amplitude Analysis	Thickness Change	Muscle Compression
1	0.6029	0.5	High
2	1	0.25	High
3	0.8529	0.5	High
4	0.3971	1	High
5	0.3676	0.25	High
6	0.2058	0.25	High
7	0.3676	0.25	High
8	0.25	0.4	High

Per Unit Values for the EMG and US (With Load)

Correlation between EMG and Thermal Imaging (TI)

Subject	Without Load				
	Thermal Imaging		EMG		
	Before	After	AA	MAV	RMS
1	0.8925	0.8964	0.0721	0.0648	0.0731
2	0.9763	0.9793	0.1912	0.1852	0.194
3	0.9753	0.9901	0.0471	0.0444	0.0493
4	0.9753	1	0.1397	0.1315	0.1418
5	0.9714	0.9842	0.1824	0.1667	0.1791
6	0.9645	0.9862	0.1059	0.1019	0.1075
7	0.9339	0.9487	0.0956	0.0852	0.097
8	0.9428	0.9458	0.0515	0.0537	0.0522

Per Unit Values for the TI and EMG (Without Load)

Subject	With Load				
	Thermal Imaging		EMG		
	Before	After	AA	MAV	RMS
1	0.979	1	0.6029	0.5556	0.6119
2	0.974	0.976	1	1	1
3	0.956	0.96	0.8529	0.8704	0.8657
4	0.969	0.974	0.3971	0.3333	0.4179
5	0.961	0.966	0.3676	0.3148	0.3731
6	0.951	0.985	0.2058	0.213	0.209
7	0.916	0.9319	0.3676	0.3519	0.3881
8	0.928	0.9399	0.25	0.2593	0.2537

Per Unit Values for the TI and EMG (With Load)

- Two modalities were compared: With Load and Without Load.
- Proportional correlation.
- Both the modalities showed an increased during the muscle contraction using load.
- The results showed a good performance.

Correlation between Thermal Imaging (TI) and Ultrasound (US)

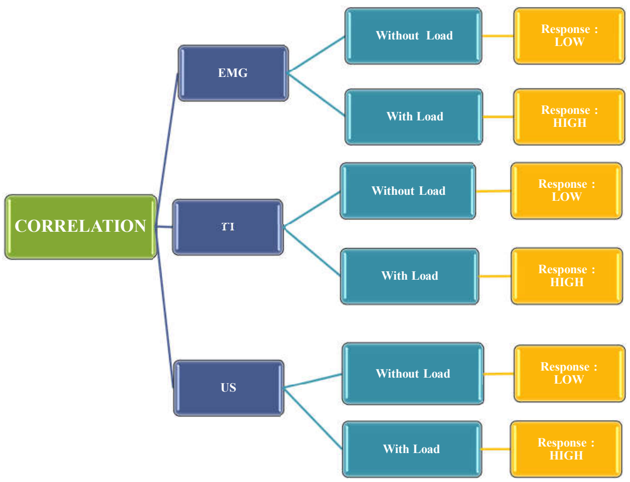
Subject	Without Load			
	Thermal Imaging		Ultrasound	
	Before	After	Thickness Change	Muscle Compression
1	0.8925	0.8964	0.8	Low
2	0.9763	0.9793	0.6	Low
3	0.9753	0.9901	0.48	Low
4	0.9753	1	1	Low
5	0.9714	0.9842	0.4	Low
6	0.9645	0.9862	0.4	Low
7	0.9339	0.9487	0.24	Low
8	0.9428	0.9458	0.24	Low

Per Unit Values for the TI and US (Without Load)

Subject	With Load			
	Thermal Imaging		Ultrasound	
	Before	After	Thickness Change	Muscle Compression
1	0.979	1	0.5	High
2	0.974	0.976	0.25	High
3	0.956	0.96	0.5	High
4	0.969	0.974	1	High
5	0.961	0.966	0.25	High
6	0.951	0.985	0.25	High
7	0.916	0.9319	0.25	High
8	0.928	0.9399	0.4	High

Per Unit Values for the TI and US (With Load)

Correlation between EMG, Thermal Imaging and Ultrasound



Conclusion

- A significant and relevant **proportional relationship** between the EMG, TI and US was identified.
- It can be stated that EMG, TI and US is a promising option to **quantitatively estimate the muscle strength.**
- All the **three modalities were strongly correlated** with its muscle strength level (MSL).
- The results of the correlation shows that there is increase in **amplitude for EMG**; **increase in temperature** for TI and also **increase in muscle compression** for the US when the muscle is contracted **using load.**

- The results and analysis of the correlation rev that it showed a very **good relationship** (performance) on the muscle contractibility.
- A **mathematical function** is generated from the correlation of the three modalities.
- The function is given by the equation below;

$$Muscle\ Contractibilty, M_c \propto f(E_A, T_I, \frac{1}{h})$$

- It is proven that the contractibility of muscle is **proportional** to the **increase of temperature** of thermal imaging, **amplitude for the EMG**, and **muscle compression change for the ultrasound when a force (load)** is applied to the muscle during its contraction.

Future Works / Recommendation

- Involve a group of large number of subjects.
- Multiple load variables.
- Other anatomical parts of human body.
- Muscle fatigue measurement.
- Can be applied in Injury identification/mapping in the future.

THANK YOU