Parameter standardization and Quantification of EMG signals for detection of muscle function of Knee Osteoarthritis Subjects

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Abstract
Electromyography (EMG) signal representing the muscular activity plays a vital role in diagnosing various diseases and also in research activities. Hence, for proper analysis of EMG signals various parameters have to be extracted which helps in analysis and in turn speeds up the process of analysis when the extraction of parameters are automated. In this study, novel parameters that are standardized are start of wave and end of wave indicating the muscle activation duration, time and amplitude for the first and the last signal peak and finally, count of peaks with amplitude being greater than the 40% and 50% of highest peak in the EMG signal. These parameters are quantified by considering signals from subjects suffering knee Osteoarthritis and as a future work these parameters and their quantified values can be considered while analyzing signals from normal subjects and from subjects suffering with knee Osteoarthritis

Keywords: EMG signal analysis, Knee Osteoarthritis, novel parameters

1. Introduction

Electromyography (EMG) signal gives a measure of the electric current that is generated in the muscles due to contraction and this represents neuromuscular activities. The information contained in EMG signal is clinically useful that can be used for both diagnosis and research activities. Two types of EMG recording are intramuscular EMG and surface EMG. One of the simplest approaches of intramuscular EMG recording is through monopolar needle electrode, which happens to be a fine wire that is inserted into a muscle. In addition, a surface electrode has a reference. Surface EMG signals assess the function of a muscle by recording muscle activity on the skin surface [1]. The surface EMG is widely used for the assessment of muscular activity during several types of movement tasks and is very useful in the gait analysis, due to its non-invasiveness which allows the subject to walk in a full physiological way [2-4]. The quantified assessment of this surface EMG helps in research activities and detection of diseases.

Knee Osteoarthritis (OA) is the most common disorder affecting elderly people. Pain, stiffness and restriction of movements are the features of knee OA. Subjects suffering from Knee OA have profound effect on physical and psychological quality of life. Their mobility is restricted and it is known to affect normal domestic activities and hence causes decrease in overall normal lifestyle [5 - 7]. X-rays, Magnetic resonance Imaging are the main investigations that are usually done to evaluate the joint for OA. Biomarkers assays are also done to know the inflammatory status around the joint. The muscle around the joint are usually affected because of the low grade inflammation and also the pain around the joint which could rest the movements around the joint. EMG is an important investigating tool to evaluate the function of the muscles around the knee joint [3]. Though EMG is used to evaluate the muscles, the standard parameters that are

used to measure the functions of muscles are limited. There is need for more parameters which can describe the muscle functions and its activity.
In this study the novel parameters which indicate the muscle functioning of subjects with knee OA are described.

2. Significance of the Study

Novel parameters like start of wave, end of wave, peak markings and the number of peaks count are extracted manually by clinical practitioners. Obtaining the necessary values is thus time consuming and prone to human errors. Thus there is necessity for development of efficient tool that calculates the required values quickly, marks the peaks as per the threshold defined and with less error from the annotated images.

3. Review of Related Studies

In a study by Sharma et al, it was reported that knee OA subjects walk with increased hamstring muscle activity and reduced quadriceps recruitment [8]. Biceps Femoris (BF), Vastus Lateralis (VL), Vastus Medialis (VM) and Semitendinosus (SMT) muscles were considered for EMG analysis during gait cycle. Altered neuro-muscular control around the Knee has been reported to interfere with normal load distribution and promote disease progression in the knee joints.
Mau-Moeller A et al have mentioned that knee OA is commonly associated with the quadriceps muscle dysfunction which in turn results in changes in motor performance [9]. Knee OA affects neuromuscular function of the quadriceps muscle during different contraction intensities, it was associated with a deterioration and neuromuscular activation. Also, EMG-torque relationship was seen to be altered and quadriceps muscles performed better.
In a study by Balshaw et al, the reliability test of surface EMG amplitude from whole quadriceps and individual muscle was conducted [10]. This test was done at the time of evoked as well as voluntary contractions. The muscles considered were from average of two distinct recording sites as well as single site. It was reported that for EMG measurements from large muscles, averaging the recording of two distinct sites is recommended as it improves within-participant reliability.
Davison MJ et al say that intramuscular fat and thigh lean muscle were concerned in the injury of physical function as seen in subjects with knee osteoarthritis [11]. In women with knee osteoarthritis, neither intramuscular nor intermuscular fat but the thigh lean muscle mass is linked to flexor power as well as knee extensor.

In a study carried out by Perraton L et al, it was observed that subjects having reconstruction of anterior cruciate ligament had dysfunction of quadriceps and this resulted in posttraumatic knee OA as well as physical disability [12]. Pamukoff DN et al in their study have mentioned that hamstrings EMG amplitude, EMG central activation ratio and amplitude of quadriceps were evaluated and found to be defective in times of maximal voluntary isometric knee extension [13]. According to Wellsandt E et al, a musculoskeletal model based on electromyography was employed for estimation of joint contact forces [14]. External Knee Adduction Moment (KAM) was found to be contributing significantly in the prediction of medial compartment contact forces in both limbs.
In the study by Ota et al, it was reported that for prevention of knee OA, gait modifications were done to reduce the KAM [15]. To prevent medial Knee OA, a useful strategy could be Nanba gait (wearing kimono) modification to reduce KAM with high activation of the hip joint and trunk muscles. Learning and standard procedure followed from the articles [21-24]
Some researchers have employed discrete wavelet, decision tree, rotation forest etc for signal classification and also developed Graphical User Interface to display the deliverables. This could be a significant step towards the automation of the process of EMG signal analysis and its applications [16 - 20].

4. Objectives of the Study

- To design a single channel surface EMG acquisition module
- To automate the process of extraction of features (from the acquired signals) that are of interest for a doctor in analyzing a disease in the early stages and thus speed up the process of feature extraction, reduce the manual effort involved in feature extraction and also reduce the human error that might occur while manually extracting the features.

5. Hypotheses of the Study

- Awareness of quantification of knee muscle functionality is minimal among clinical practitioners.
- Currently the parameters extracted from EMG signals is limited in number and providing more parameters would help in better quantification of the signal, which in turn helps in reliable detection of knee osteoarthritis.

6. Population and Sample

The subjects with confirmed knee OA were considered for acquisition of signals for further analysis. The dataset of 24 subjects in both gender in the age group of 45-75 years were participants of this study. EMG signals of knee muscles have been recorded for both the left and right leg for duration of 10 seconds. From each leg, signal recordings from Rectus femoris, Vastus lateralis and Vastus medialis muscles were done. So, in this way for each subject there are three signals from left leg and three signals from right leg. On the whole, 6 signals per subject are considered for the further analysis. The user selected, recorded EMG signal can be loaded into the MATLAB software for further analysis on the signal. The recorded surface EMG signal that is loaded into the MATLAB software is shown in Fig. 1.

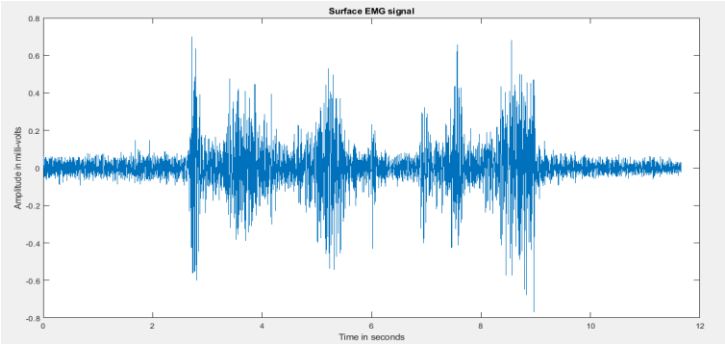

Fig. 1: Surface EMG signal that is imported into MATLAB

6.1. Data Analysis and Interpretation

The loaded surface EMG signal is processed to extract following features:

a) Start of wave and end of wave:

The exact instant of time at which the muscle activation starts and ends, that is, the start and end of wave is marked on the basis of user's analysis. This is coded by accepting two inputs from the user. The user needs to analyse the signal and click on the signal where he/she assumes the start and end of activity. Based on these inputs from the user, the MATLAB code returns output indicating the instant of time for the marking done by the user. Fig. 2 shows the time instant (in seconds) at which the muscle activation starts and ends for the signal that is loaded for signal processing.

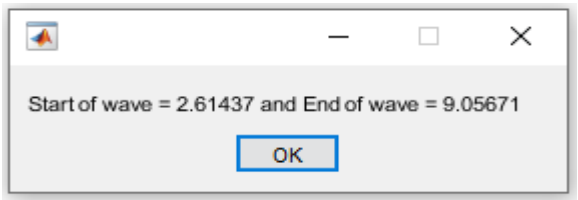

Fig. 2: Time instant at which wave starts and ends

b) Marking of signal peaks and count number of peaks:

The sEMG signal peaks are marked by the MATLAB code for various threshold values. Any peak whose amplitude is greater than the given threshold value is marked as a peak and number of such peaks per threshold value is provided as an output. The threshold values considered for this work are 0.2, 0.3,

0.4, 0.5 and values equal to 50% and 40% of maximum peak. The marking of signal peaks with 0.5 mV and the count of number of peaks is shown in Fig. 3 and Fig. 4.

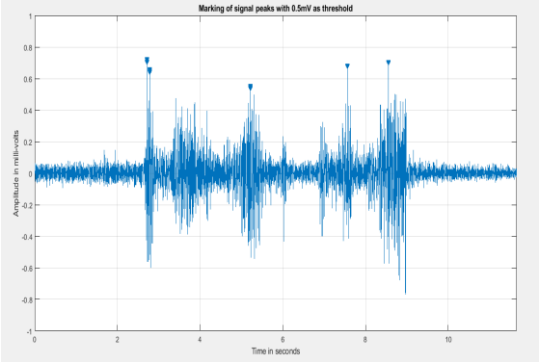

Fig. 3: Marking of signal peak with 0.5mV as threshold

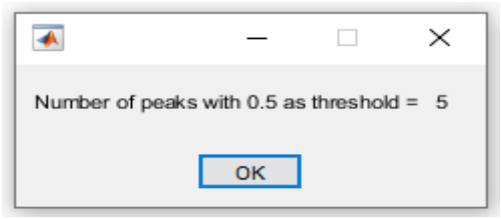

Fig. 4: Count of number of signal peaks

c) Time and amplitude for first and last peak:

The time to first peak and time for the last peak is marked by the MATLAB code. This output also provides information about amplitude of the first and last peak. The time instant and amplitude for first peak and the last peak is shown in Fig. 5.

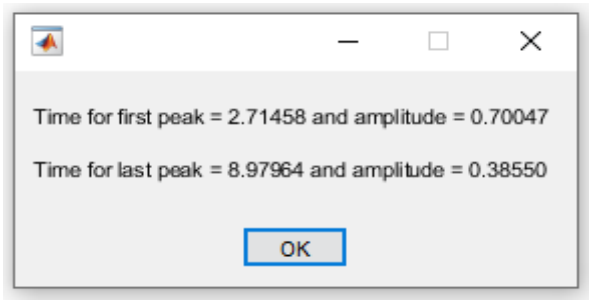

Fig. 5: Time and amplitude for first and last peak

The extracted feature values are displayed to the user with the help of message box. The values are as well saved into an Excel sheet with its file name same as the input signal file name and saved at the location from where the input is imported into MATLAB. One excel file is generated for one input signal

7. Results and discussion

The maximum (MAX), minimum (MIN), mean and standard deviation (STDDEV) values for standardized novel parameters extracted from left and right leg of muscles: Rectus femoris, Vastus lateralis and Vastus medialis are described in table 1 to 6.

Table 1: Parameters for assessment of functions for muscle on left side Rectus Femoris

Parameter	**MAX**	**MIN**	**MEAN**	**STDDEV**
Time for first peak (in seconds)	4.619125	0.54381	2.131375	1.014889
First peak amplitude (mV)	0.700531	0.200104	0.286695	0.14111
Time for last peak (in seconds)	11.11163	4.03775	7.209442	2.017492
Last peak amplitude (mV)	0.436737	0.203461	0.249371	0.067536
Count of peaks having amplitude more than 50% of highest peak	84	4	32.125	22.89734
Count of peaks having amplitude more than 40% of highest peak	211	11	69.45833	54.94264
Start of wave (in seconds)	4.412442	0.383641	1.974157	1.017864
End of wave (in seconds)	13.46408	5.153226	7.95237	2.26664

For EMG signal from Rectus femoris muscle on the left leg from subject with knee OA, may have mean muscle activation duration of 5.978 seconds with muscle activation starting around 1.97 seconds and ending around 7.95

seconds. Also, the time and amplitude for the first peak are 2.13 and 0.29 respectively while those for last peak are 7.21 and 0.25 respectively. On an average, there could be 32.13 and 69.46 number of peaks whose amplitudes are greater than 50% and 40% of highest peak respectively.

Table 2: Parameters for assessment of functions for muscle on right side Rectus Femoris

Parameter	**MAX**	**MIN**	**MEAN**	**STDDEV**
Time for first peak (in seconds)	5.736125	0.000612	2.156725	1.513146
First peak amplitude (mV)	0.483276	0.207123	0.278837	0.077572
Time for last peak (in seconds)	13.53825	2.739625	7.662373	2.516839
Last peak amplitude (mV)	0.436127	0.201569	0.254052	0.053954
Count of peaks having amplitude more than 50% of highest peak	84	2	27.54167	16.76948
Count of peaks having amplitude more than 40% of highest peak	173	2	54.41667	34.139
Start of wave (in seconds)	5.239631	0.042533	1.825456	1.257632
End of wave (in seconds)	13.87429	2.975806	7.959067	2.406482

For EMG signal from Rectus femoris muscle on the right leg from subject with knee OA, may have mean muscle activation duration of 6.13 seconds with muscle activation starting around 1.83 seconds and ending around 7.95 seconds. Also, the time and amplitude for the first peak are 2.15 and 0.27 respectively while those for last peak are 7.66 and 0.25 respectively. On an average, there could be 27.54 and 54.42 number of peaks whose amplitudes are greater than 50% and 40% of highest peak respectively.

Table 3: Parameters for assessment of functions for muscle on left side Vastus lateralis

Parameter	**MAX**	**MIN**	**MEAN**	**STDDEV**
Time for first peak (in seconds)	4.77812	0.07937	2.1556	1.1246
First peak amplitude (mV)	0.38006	0.20074	0.2665	0.059927
Time for last peak (in seconds)	13.1388	4.42562	9.1036	2.791245
Last peak amplitude (mV)	0.38028	0.20251	0.2535	0.055589
Count of peaks having amplitude more than 50% of highest peak	97	7	43.417	28.20718
Count of peaks having amplitude more than 40% of highest peak	203	13	87.833	54.0279
Start of wave (in seconds)	4.543951	0.09331	2.0746	1.021635
End of wave (in seconds)	13.70392	4.76958	8.8355	2.708999

For EMG signal from vastus lateralis muscle on the left leg from subject with knee OA, may have mean muscle activation duration of 6.76 seconds with muscle activation starting around 2.07 seconds and ending around 8.83 seconds. Also, the time and

amplitude for the first peak are 2.15 and 0.27 respectively while those for last peak are 9.1 and 0.25 respectively. On an average, there could be 43.42 and 87.83 number of peaks whose amplitudes are greater than 50% and 40% of highest peak respectively.

Table 4: Parameters for assessment of functions for muscle on right side Vastus lateralis

Parameter	MAX	MIN	MEAN	STDDEV
Time for first peak (in seconds)	3.999125	0.001134	1.8325	1.112805
First peak amplitude (mV)	0.407684	0.201416	0.2492	0.054328
Time for last peak (in seconds)	12.51713	4.263875	8.7197	2.389808
Last peak amplitude (mV)	0.549744	0.200897	0.2355	0.070029
Count of peaks having amplitude more than 50% of highest peak	102	4	43.625	23.62352
Count of peaks having amplitude more than 40% of highest peak	226	21	82.958	46.4332
Start of wave (in seconds)	3.734405	0.262673	1.7438	0.903938
End of wave (in seconds)	14.46975	4.510369	8.7220	2.896051

For EMG signal from vastus lateralis muscle on the right leg from subject with knee OA, may have mean muscle activation duration of 6.98 seconds with muscle activation starting around 1.74 seconds and ending around 8.72 seconds. Also, the time and amplitude for the first peak are 1.83 and 0.25 respectively while those for last peak are 8.72 and 0.23 respectively. On an average, there could be 43.62 and 82.95 number of peaks whose amplitudes are greater than 50% and 40% of highest peak respectively.

Table 5: Parameters for assessment of functions for muscle on left side Vastus medialis

Parameter	MAX	MIN	MEAN	STDDEV
Time for first peak (in seconds)	5.2261	0.005125	1.531569	1.274573
First peak amplitude (mV)	0.3134	0.200836	0.233457	0.031833
Time for last peak (in seconds)	19.133	4.841	8.846716	3.505673
Last peak amplitude (mV)	0.3379	0.203339	0.230091	0.034675
Count of peaks having amplitude more than 50% of highest peak	161	15	47.33333	37.34873
Count of peaks having amplitude more than 40% of highest peak	215	25	90.20833	58.27146
Start of wave (in seconds)	4.6871	0.028355	1.619492	1.168331
End of wave (in seconds)	19.121	4.043779	8.708374	3.772381

For EMG signal from vastus medialis muscle on the left leg from subject with knee OA, may have mean muscle activation duration of 7.09 seconds with muscle activation starting around 1.62 seconds and ending around 8.71 seconds. Also, the time and amplitude for the first peak are 1.53 and 0.23

respectively while those for last peak are 8.85 and 0.23 respectively. On an average, there could be 47.33 and 90.21 number of peaks whose amplitudes are greater than 50% and 40% of highest peak respectively.
For EMG signal from vastus medialis muscle on the right leg from subject with knee OA, may have mean muscle activation duration of 7.09 seconds with muscle activation starting around 2.12 seconds and ending around 9.22 seconds. Also, the time and amplitude for the first peak are 1.82 and 0.28 respectively while those for last peak are 8.93 and 0.29 respectively. On an average, there could be 45.5 and 88.5 number of peaks whose amplitudes are greater than 50% and 40% of highest peak respectively.

Table 6: Parameters for assessment of functions for muscle on right side Vastus medialis

Parameter	**MAX**	**MIN**	**MEAN**	**STDDEV**
Time for first peak (in seconds)	4.877375	0.00023	1.8241	1.236373
First peak amplitude (mV)	0.587524	0.20062	0.2845	0.128488
Time for last peak (in seconds)	19.14444	4.26387	8.9299	4.359273
Last peak amplitude (mV)	0.696899	0.20007	0.2890	0.156595
Count of peaks having amplitude more than 50% of highest peak	116	9	45.5	27.28114
Count of peaks having amplitude more than 40% of highest peak	222	12	88.5	46.84387
Start of wave (in seconds)	4.678639	0.30069	2.1223	1.414526
End of wave (in seconds)	19.42396	4.40668	9.2174	4.427688

8. Conclusion

Novel parameters that are standardised and quantify the EMG signals in the process of analysing signals from subjects suffering from knee OA are start of wave, end of wave, number of peaks that are greater than 50% and 40% of highest peak, time and amplitude for the first and last peak. This shows that any subject suffering from knee OA can expect values for these standardised parameters around the mean values mentioned with +/- standard deviation. As a future work these novel standardised parameters and their mean values can be considered for comparing normal subjects against subjects suffering from knee OA.

References

[1] Rashid, S.A., Hussain, M.E., Bhati, P. et al. Muscle activation patterns around knee following neuromuscular training in patients with knee osteoarthritis: secondary analysis of a randomized clinical trial (2022). Arch Physiother 12: 19.
[2] Yilmaz OO, Senocak O, Sahin E, Baydar M, Gulbahar S, Bircan C, Alper S (2010). Efficacy of EMG-biofeedback in knee osteoarthritis. Rheumatol Int.;30(7):887-92. doi: 10.1007/s00296-009-1070-9. Epub 2009 Aug 20. PMID: 19693508.
[3] Ghazwan A, Wilson C, Holt CA, Whatling GM. Knee osteoarthritis alters peri-articular knee muscle strategies during gait (2022). PLoS One. 17(1): e0262798.
[4] Jin Ju Kim, Han Cho, Yulhyun Park, Joonyoung Jang, Jung Woo Kim, Ju Seok Ryu (2020). Biomechanical influences of gait patterns on knee joint: Kinematic & EMG analysis, 15(5): e0233593.
[5] Al Amer, H.S., Sabbahi, M.A., Alrowayeh, H.N. et al. Electromyographic activity of quadriceps muscle during sit-to-stand in patients with unilateral knee osteoarthritis (2018). BMC Res Notes 11(1): 356.
[6] Heidari B (2011). Knee osteoarthritis prevalence, risk factors, pathogenesis and

features. Part I. Caspian J Intern Med. 2(2):205–12.
[7] Hayami T (2008). Osteoarthritis of the knee joint as a cause of musculoskeletal ambulation disability symptom complex (MADS) Clin Calcium; 18:1574–80.
[8] Sharma SK, Yadav SL, Singh U, Wadhwa S (2017). Muscle Activation Profiles and Co-Activation of Quadriceps and Hamstring Muscles around Knee Joint in Indian Primary Osteoarthritis Knee Patients. J Clin Diagn Res. 11(5):RC09–14.
[9] Mau-Moeller A, Jacksteit R, Jackszis M, Feldhege F, Weippert M, Mittelmeier W, et al (2017). Neuromuscular function of the quadriceps muscle during isometric maximal, submaximal and submaximal fatiguing voluntary contractions in knee osteoarthrosis patients. PLoS ONE.12(5): e0176976.
[10] Balshaw TG, Fry A, Maden-Wilkinson TM, Kong PW, Folland JP (2017). Reliability of quadriceps surface electromyography measurements is improved by two vs. single site recordings. Eur J Appl Physiol. 117(6):1085–94.
[11] Davison MJ, Maly MR, Keir PJ, Hapuhennedige SM, Kron AT, Adachi JD, et al (2017). Lean muscle volume of the thigh has a stronger relationship with muscle power than muscle strength in women with knee osteoarthritis. Clin Biomech (Bristol, Avon). 2017 Jan;41:92–7.
[12] Perraton L, Clark R, Crossley K, Pua Y-H, Whitehead T, Morris H, et al (2017). Impaired voluntary quadriceps force control following anterior cruciate ligament reconstruction: relationship with knee function. Knee Surg Sports Traumatol Arthrosc. 25(5):1424–31.
[13] Pamukoff DN, Pietrosimone BG, Ryan ED, Lee DR, Blackburn JT (2017). Quadriceps Function and Hamstrings Co-Activation After Anterior Cruciate Ligament Reconstruction. J Athl Train. 52(5):422–8.
[14] Wellsandt E, Khandha A, Manal K, Axe MJ, Buchanan TS, Snyder-Mackler L (2017). Predictors of knee joint loading after anterior cruciate ligament reconstruction. J Orthop Res. 35(3):651–6.
[15] Ota S, Ogawa Y, Ota H, Fujiwara T, Sugiyama T, Ochi A (2017). Beneficial effects of a gait used while wearing a kimono to decrease the knee adduction moment in healthy adults. PLoS ONE. 12(6):e0179260.
[16] Kaur, Manvinder, ShilpiMathur, Dinesh Bhatia, and Suresh Verma (2015). "siGnum: Graphical user interface for EMG signal analysis." Journal of medical engineering & technology 39, no. 1: 19-25.
[17] Gokgoz, Ercan, and AbdulhamitSubasi (2015). "Comparison of decision tree algorithms for EMG signal classification using DWT." Biomedical Signal Processing and Control 18: 138-144.
[18] Mengarelli, Alessandro, Stefano Cardarelli, Federica Verdini, Laura Burattini, Sandro Fioretti, and Francesco Di Nardo (2016). "A MATLAB-based graphical user interface for the identification of muscular activations from surface electromyography signals." 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 3646-3649. IEEE.
[19] Belkhou, Abdelali, Atman Jbari, and LarbiBelarbi (2017). "A continuous wavelet based technique for the analysis of electromyography signals." In 2017 International Conference on Electrical and Information Technologies (ICEIT), pp. 1-5. IEEE.
[20] Subasi, Abdulhamit, and EmineYaman (2019). "EMG Signal Classification Using Discrete Wavelet Transform and Rotation Forest." In International Conference on Medical and Biological Engineering, pp. 29-35. Springer, Cham.
[21] R, Raghavendra; et. al.-"Web Information Extraction methods using Web Content Mining (WCM) for Web Applications" International Journal of Computing and Digital Systems, ISSN: 2210-142X 2022, 11(1), pp. 609–623 DOI: https://dx.doi.org/10.12785/ijcds/110149
[22] V. K. Reshma, Ihtiram Raza Khan, M. N, Puneet Kumar Aggarwal, S. Hemalatha, Khalid K. Almuzaini, Enoch Tetteh Amoatey, "Hybrid Block-Based Lightweight Machine Learning-Based Predictive Models

for Quality Preserving in the Internet of Things- (IoT-) Based Medical Images with Diagnostic Applications", Computational Intelligence and Neuroscience, vol. 2022, Article ID 8173372, 14 pages, 2022. https://doi.org/10.1155/2022/8173372

[23] B. K. Nirupama and et. al. "Network Intrusion Detection using Decision Tree and Random Forest," 2022 International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI), 2022, pp. 1-9, doi: 10.1109/ACCAI53970.2022.9752578.

[24] S. K. Sunori et al., "Unsupervised and Supervised Learning based Classification Models for Air Pollution Data," 2021 2nd Global Conference for Advancement in Technology (GCAT), 2021, pp. 1-5, doi: 10.1109/GCAT52182.2021.9587793