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MEASUREMENT OF HUMAN LEG JOINT ANGLE THROUGH MOTION BASED ON ELECTROMYOGRAPHY (EMG) SIGNAL[1]

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Abstract

Surface electromyography (SEMG) measurement technique for the signal was produced through the contraction of muscles in a human body. The surface electrode is connected on the skin of the muscle. This paper presents an off-line design for the estimation of the actual joint angle of a human leg obtained in performing flexion-extension of the leg at slow and high speeds movement. The design is composed of two phases. The first is measurement of real EMG signal of human leg performance by using SEMG technique and processing this signal with filtering, amplification and then normalized with maximum amplitude. The second phase is to design an artificial neural network (ANN) and train it to predict the joint angle from the parameters extracted from the SEMG signal. Three main parameters of EMG signal are used in the prediction process: Number of turns in a specific time period, duration of signal repetition and amplitude of signal. The design of ANN includes the identification of a performing human leg EMG signal with two speed levels (slow-fast) and estimation of knee joint angle by recognition process depending on the parameters of real measured EMG signal. The real EMG signal is measured from full leg-extension to full leg-flexion by (3 sec) with slow motion and (1 sec) at fast motion.

Root mean square (RMS) errors were calculated between the actual angle (measured by the trigonometric formula was applied with any human leg gives real EMG signal measurement) and the angle predicted by the neural network design. This design is simulated by using MATLAB Ver. R2010a, and satisfying results are obtained. That explains the ability of estimation of joint angle for human leg, where the RMS errors are obtained from (0.065) to (0.015) at fast speed leg flexion -extension and from (0.018) to (0.0026) at slow speed leg flexion-extension.

Keywords: Surface Electromyography (SEMG), Artificial Neural Network (ANN).

قياس زاوية مفصل ساق بشري أثناء الحركة على أساس أشارة التحفيز العضلي

الخلاصة

تقنية قياس أشارة التحفيز العضلي باستخدام المتحسس السطحي إثناء تقلص عضلات الجسم البشري الذي يربط على الجلد المغطي للعضلة. هذا البحث يقدم تصميم لتخمين زاوية المفصل للساق البشري التي تحصل نتيجة انقباض – انبساط الساق عند الحركة البطيئة والسريعة. هذا التصميم يتكون من طورين الأول هو قياس أشارة التحفيز الحقيقة وإدخالها على عمليات عديدة كالتنقية والتكبير والتسوية مع أعلى قيمة للإشارة أما الطور الثاني فيضم تصميم شبكة عصبية صناعية وتدريبها لتخمين زاوية المفصل بالاعتماد على ثلاث خواص رئيسية (عدد القمم في فترة محددة ، فترة الإشارة ، مستوى الإشارة) لإشارة التحفيز للعضلات التي تسبب الحركة (التقلص أو الانبساط) وتصميم التخمين باستخدام الخلايا العصبية الصناعية يتضمن عملية التعليم والتعريف للإشارة التحفيز وعملية التخمين لقيمة الزاوية إثناء الحركة السريعة والتي قدرت بحوالي ثانية واحدة كحركة انقباض وانبساط وحوالي 3 ثانية كحركة بطيئة .

تمت المقارنة بين درجة الخطأ في التخمين مع القياس الحقيقي لزاوية المفصل والتي حسبت بطريقة المثلثات، تمت محاكاة هذا التصميم باستخدام الماتلاب 2010a وحصلت على نتائج مرضية تبين إمكانية اعتماد هذا التصميم لقياس زاوية المفصل إثناء الحركة بالاعتماد على إشارة التحفيز العضلي لبعض العضلات المسببة لهذه الحركة حيث كانت نسبة الخطأ في الحركة البطيئة تتراوح (0.0026) - (0.018) وفي الحركة السريعة (0.065)-(0.015) .

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1-Introduction

Surface electromyography (SEMG) signals provide a non-invasive tool for investigating the properties of skeletal muscles. The bandwidth of the recorded potentials are relatively narrow (50-500 Hz), and their amplitude is low (50 µV - 5 mV). These signals have been used not only for monitoring muscle behavior during rehabilitation programs, but also for the mechanical control of prostheses. In this context, it is important to be able to correctly predict which movement is intended by the user. The SEMG signal is very convenient for such application, because it is noninvasive, simple to use, and intrinsically related to the user's intention. However, there are other useful variables, especially those related to proprioception, for example: the angle of a joint, the position of the limb, and the force being exerted [1,2].

Specifically, for the development of an active leg prosthesis that also possesses ankle and foot axes, it is necessary to use other sources of information besides SEMG. Thus, the use of myoelectric signals combined with other variables related to proprioception may improve the reliability in closed-loop control systems. Fig.1. presents the typical main components of general myoelectric pattern recognition.

The SEMG signals are acquired by surface electrodes placed on the skin over muscle(s) of the user. The signals originating from the electrodes are pre-amplified to differentiate the small signals of interest, and then are amplified, filtered and digitized. Finally, the information is transferred to a myoelectric controller [3].

The knee joint is one of the most complex synovial joints that exist in the human body whose main functions are: to permit the movement during the locomotion, and to allow the static stability. The mobility associated with the knee joint is indispensable to human locomotion and it helps correct foot orientation and positioning in order to overcome the possible ground irregularities. In the knee articulation, there are three types of motion, namely, flexion, rotation, and sliding of the patella. The knee joint includes three functional compartments, medial, lateral, and patello-femoral, which make the knee quite susceptible to injures and chronic disease, such as displacement, arthritis, ligaments rupture, and menisci separation. In fact, the greatest number of human ligament injuries occurs in ligaments of the knee. The knee joint is surrounded by a joint capsule with ligaments strapping the inside and outside of the joint (collateral ligaments) as well as crossing within the joint (cruciate ligaments). [4].

The muscles of the lower limbs are larger and more powerful than those of the upper limbs. These muscles can be divided into three groups and they are shown in Fig.2. [5,6]:

–Muscles that move the thigh.
–Muscles that move the leg.
–Muscles that move the foot and toes.

Movements of the knee:

The principal knee movements are flexion and extension. Note that the *capsule* is attached to the margins of these articular surfaces but communicates above with the *suprapatellar bursa* (between the lower femoral shaft and the quadriceps), posteriorly with the bursa under the medial head of gastrocnemius and often, through it, with the bursa under semimembranosus. It may also communicate with the bursa under the lateral head of gastrocnemius. The capsule is also perforated posteriorly by popliteus, which emerges from it in much the same way that the long head of biceps bursts out of the shoulder joint.

The capsule of the knee joint is reinforced on each side by the *medial* and *lateral collateral ligaments*, the latter passing to the head of the fibula and lying free from the capsule. Anteriorly, the capsule is considerably strengthened by the *ligamentum* *patellae*, and, on each side of the patella, by the *medial* and *lateral patellar retinacula*, which are expansions from vastus medialis and lateralis. Posteriorly, the tough *oblique ligament* arises as an expansion from the insertion of semimembranosus and blends with the joint capsule [7,8].

2- EMG Characteristics

A motor unit action potential, or MUAPs, is a summated action potential as detected from all the muscle fibers in the same motor unit. It is the summation of all the MFAPs produced by fibers of the MU. The shape and characteristics of a MUAP are shown in Fig.3. Now the characteristics of EMG or the O/P from MUAP can be summarized. The following characteristics will be covered: Duration / Amplitude / Area / Area-Amplitude, the Area to Amplitude Ratio (AAR) [Thickness] / Size Index Firing Rate / Firing Rate per Motor Unit (FR/MU) / # of Phases / % Polyphasic MUAPs / # of Turns [8].

Now the simple explanation will present classification. The amplitude is consistently reduced or normal (5 to 850 mV) in myopathic cases, but can vary between reduced and very high for neuropathic cases. Amplitude also has correlations with other characteristics that may make it valuable to graph it on a two dimensional scatter plot with another characteristic. Amplitude and Duration are positively correlated. Amplitude and AAR are negatively correlated which leads to more separable data distributions when the two are plotted together. [8,9].

1- Real EMG Signal Measurement

There are many important parameters that must be taken under consideration in the measurement process. The most important parameter in the measurement process is selecting a position for electrodes and clinical information of the job.

A. position of electrodes:

There are nine muscles up and down of the knee joint affecting the movements of the knee. From the clinical information and practice experiential, the best position of electrodes is to recognize the maximum amplitude for flexion/extension knee joint. Fig.4 (a&b) represents practice experiment to select the position for two electrodes to get the EMG signal at the movements of joint. In this paper I used four muscles that have min effect for flexion/extension knee joint. The EMG signal is recorded by using SEMG electrodes therefore four electrodes must be used at the same moment (i.e. four channels recorded). This property is not available practically in my country therefore we used off-line technique for the estimation of joint angle by using EMG signal[10,11].

B. Recording SEMG Data:

In this paper the real SEMG signals were recorded by the following procedure:

- ➢ Record the signal with relax and no movement in the knee joint (spontaneous case).
- ➢ Record the signal from full extension to full flexion of knee joint with time (3 sec) (i.e. slow motion of leg).
- ➢ Record the signal from full extension to full flexion of knee joint with time (1 sec) (i.e. fast motion of leg).
- ➢ Repeated the items 2&3 with an angle of flexion about 45^o, 90^o, 135^o or max angle implemented from human.

Fig.5(a-d) represents the photos of SEMG signal for main leg muscles that cause flexion /extension to the knee joint and these processing are achieved by using the instruments in AL Yarmook, Educational Hospital in Baghdad.

The data for this experiential is recorded with single channel. This problem caused the design to be achieved off line where for each movement we must take four runs to get full data.

Fig.6. represent example for SEMG signal was made preparing the signal by using filtering and amplification and these processing was achieved by used EMGLab software where, it has ability for processing with real data recorded from Micromed company instrumentation that has the data format (.TRC).

4. Design of Estimation Joint Angle

The angle of Knee joint in this paper is calculated by two methods as follow: the first practice method using trigonometric relationship with the posture of human leg to get angle of knee joint before measuring the real SEMG that is used in the second design for estimating the joint angle. Fig.7. explains the geometry for human leg using the trigonometric form to calculate angle joint. This calculation is achieved with the assumption that the radius of cross section area of normal human leg with age 25 years is (r = 13 cm) [12,13] :

$$S=R\theta, \quad \theta=\frac{S}{R}; \quad \theta \; in\,rad; \quad \theta^{o}=\frac{\theta_{rad}*180}{\pi} \qquad (1)$$

Where (R) represents the length of the lower leg (from knee joint to ankle joint) and (S) represents the length of the arc from the initial position of the ankle joint to its second position, while (Ө) is the angle of flexion/extension knee joint.

The second method for estimating the angle of joint is designing by using ANN approach. Fig.8 explains the diagram of design. The design consists of two main stages:

The identification stage: From the explanation of the movement of the knee joint, there are nine muscles in the human leg which consist the movement of the joint but there are four main muscles which cause the angle joint of flexion/extension joint as follows; (Vastus medialis, Vastus lateralis for extension and Semitendinosus, Gustrocomis for flexion). The SEMG signals of the four muscles will be used in the estimation of the angle at the human leg movement.

In this paper, the Recurrent Multilayer Perception (RMLP) is used. Neural Network (NN) is used in the identification of the SEMG signals for the main four muscles. The block diagram in Fig.9 explains the details of the identification stage [14].

The NN structure (3×2$_{R}$ ×2□2□□□□□□)is shown in Fig.10, i.e. three units in layer 1 (this is input layer), two recurrent units in layer 2, and 2 units in layer 3. This network has external feedback with 2 unit delays. Sigmoidal activation functions were used for all units in both hidden and output layers. The error function which measures the difference between the neural net approximation and the desired trajectory is [14]:

$$E(w) = \frac{1}{2}\sum_{n=1}^{M}\sum_{l=1}^{L}\left[d_l(n) - y_l(n)\right]^2 \qquad (2)$$

The error function given here is called the *batch error* because it contains the sum of the errors over the entire training set; that is, the error over all time steps. The training algorithm used in this paper is backpropagation-through-time (BPTT)[14, 15].

The Recognition and Decision Stage: The test signal that is recorded from the same type of muscles will be used to estimate the angle of joint where the data base is formated by recording the SEMG of muscles with values of joint angle (0(no command from brain), π/4, π/2, and 3π/4(max movement)). After reconstructing the same features for test signal, they will be entered to the same structure of RMLP-NN with identification data base by feed forward training only. The output of these networks recognizes the muscles and the amplitude of SEMG with each sample. By using the following relation with amplitude of SEMG signal with time and taking the average between results of Vastus medialis, Vastus lateralis for extension and

Semitendinosus, Gustrocomis for flexion we will get the angle of joint at flexion and then the complement angle (extension angle). Fig.11. explains the second stage of design for estimation of knee joint angle.

$$\left.\begin{aligned}
\theta_{f_{1,2}} &= \frac{A_i * \theta_{f\max}}{A_{\max}} \\
\theta_{flexion} &= \frac{\theta_{f_1} + \theta_{f_2}}{2} \\
\theta_{E_{1,2}} &= \frac{A_i * \theta_{E\max}}{A_{\max}} \\
\theta_{Extension} &= \frac{\theta_{E_1} + \theta_{E_2}}{2}
\end{aligned}\right\} \quad (3)$$

5. Simulation Results

The simulation of the estimated design is achieved by MATLAB Var.R2010a. Fig.12. presents the identification of SEMG signals of a human leg related to the knee joint flexion/extension movement and from this figure we can see that the error approaches to zero after about nine iterations and after that there is no local minimum or increase in error. Therefore; these are the best results for the identification after some trial to adjust the learning rate and momentum term.

Two types of human leg movement according to speed of leg are used in simulation:

Low speed: the human leg in this simulation was moving from full extension to full flexion with a speed of about 3sec/cycle. Fig.13. represents the estimated values of knee flexion/extension joint angle. The calculation of the accuracy of joint angle is achieved by calculating the RMS error between estimated values and practice value measured in the first stage of the design. The RMS error has the value from (0.065) to (0.015).

High speed: the same procedure in low speed was implemented here and the results are explained in Fig.14. The RMS errors are obtained from (0.018) to (0.0026) at fast speed leg flexion –extension. Fig.15. explains the RMS values in two speeds of movement (low and high) with recorded time (180 sec, 60 sec) for low and high speed respectively.

Conclusion

From the obtained results, it can be concluded that the RMLP-NN has the ability to identify and solve the IK of a human leg with high accuracy and simplicity. The ability of estimating the angle knee joint based on SEMG with high accuracy can be used with many applications. There are many critical coefficients in the movement of the knee joint that must be taken under consideration in the estimation of angle joint. The obtained results are off-line because there is no SEMG muit-channel recorded; therefore, we must record the data of SEMG for each muscle alone and return the same command to record another muscle. If measurements and savings of SEMG muscles signal are available, we can implement this design on-line and it can be implemented as portable unit to be used with many applications.

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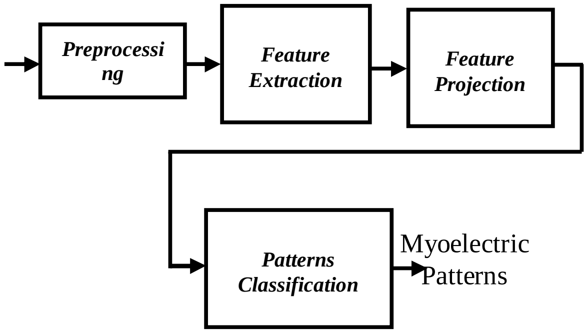


Fig.1. Typical main components of a general myoelectric controller based on pattern recognition.

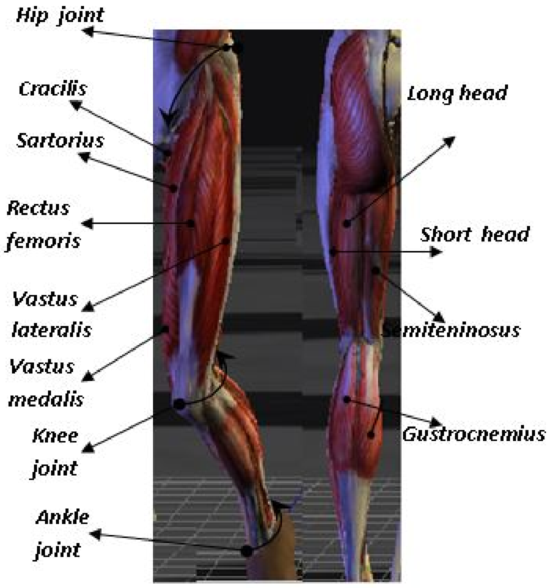


Fig.2. The Human leg muscles that caused flexion / extension knee joint [7].

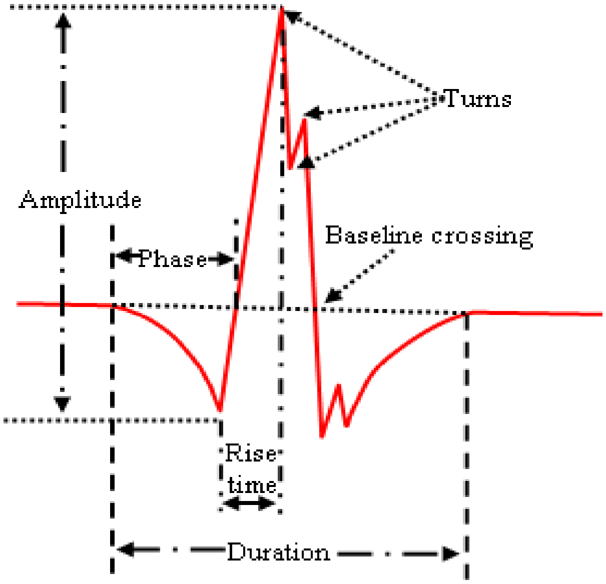


Fig.3. Characteristics of a EMG signal [9].

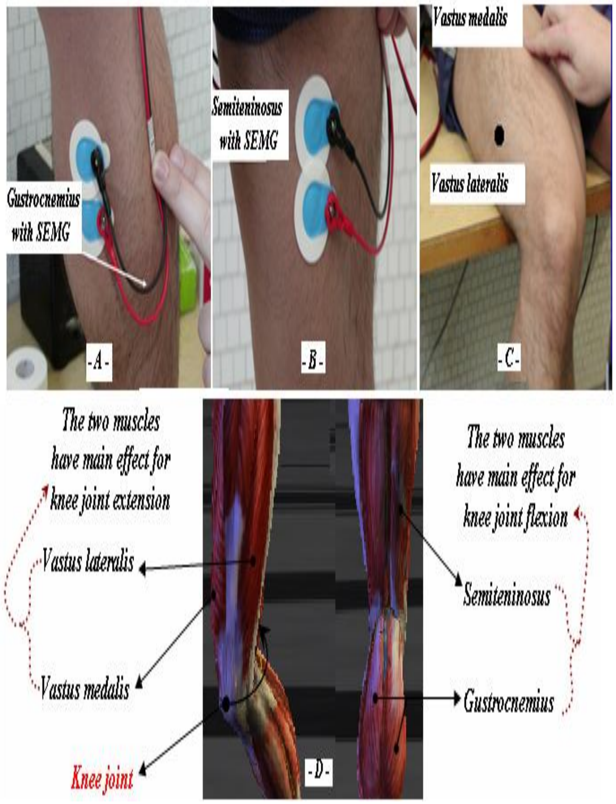
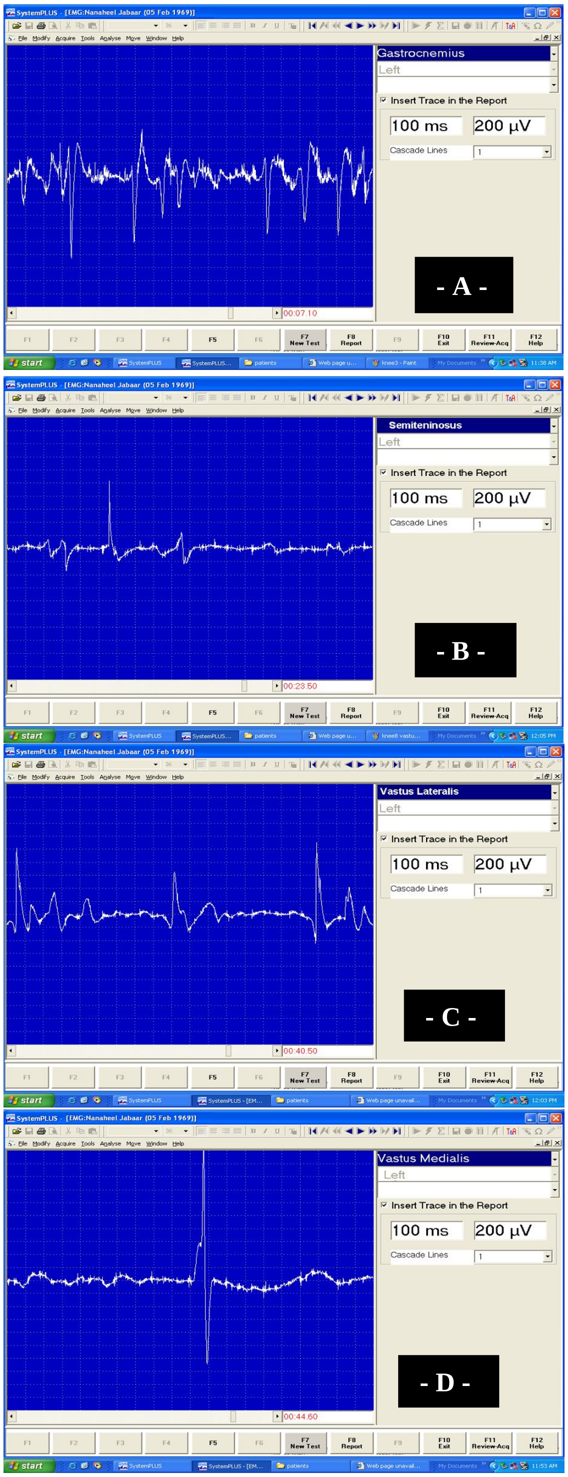


Fig.4. Location of SEMG on human leg.



Gastrocnemius
Left
☑ Insert Trace in the Report
100 ms 200 µV
Cascade Lines 1
00:07.10

Semiteninosus
Left
☑ Insert Trace in the Report
100 ms 200 µV
Cascade Lines 1
00:23.50

Vastus Lateralis
Left
☑ Insert Trace in the Report
100 ms 200 µV
Cascade Lines 1
00:40.50

Vastus Medialis
Left
☑ Insert Trace in the Report
100 ms 200 µV
Cascade Lines 1
00:44.60

Fig.5. Photo of real SEMG signal from Micrmed measurement model.

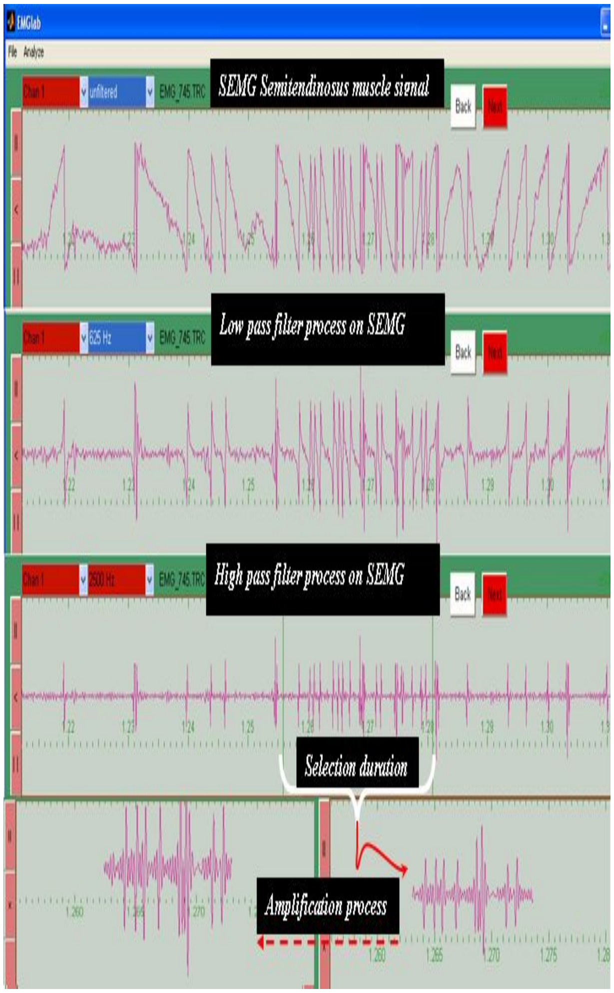
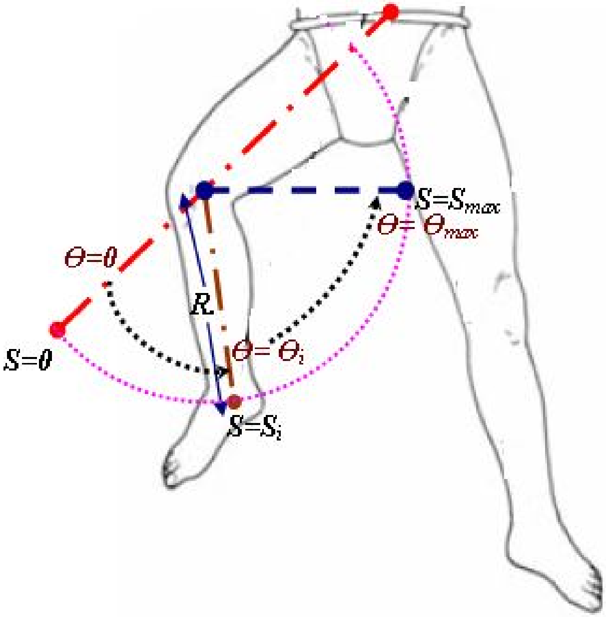


Fig.6. Real SEMG signal represent by EMGLab software.



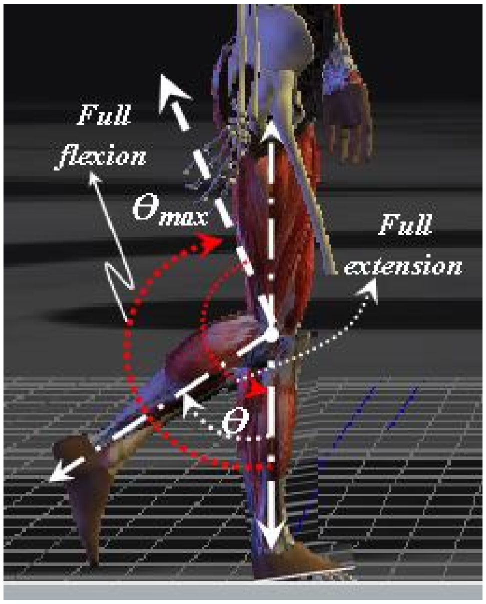


Fig.7. Geometry calculation of Knee joint angle.

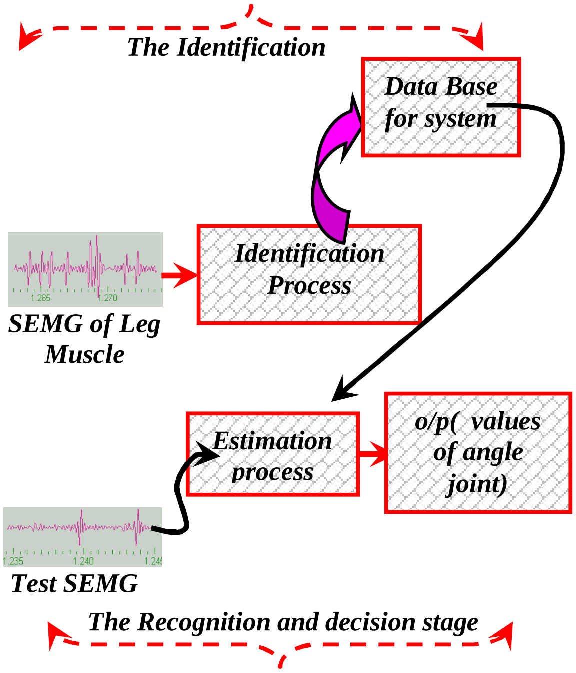


Fig.8. NN design for estimation knee joint angle.

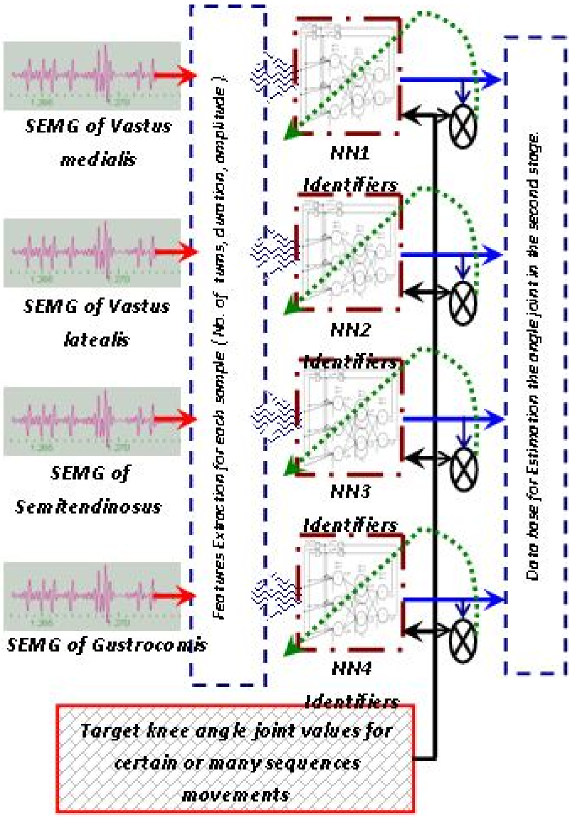


Fig.9. NN Identification of SEMG signal for human leg muscles.

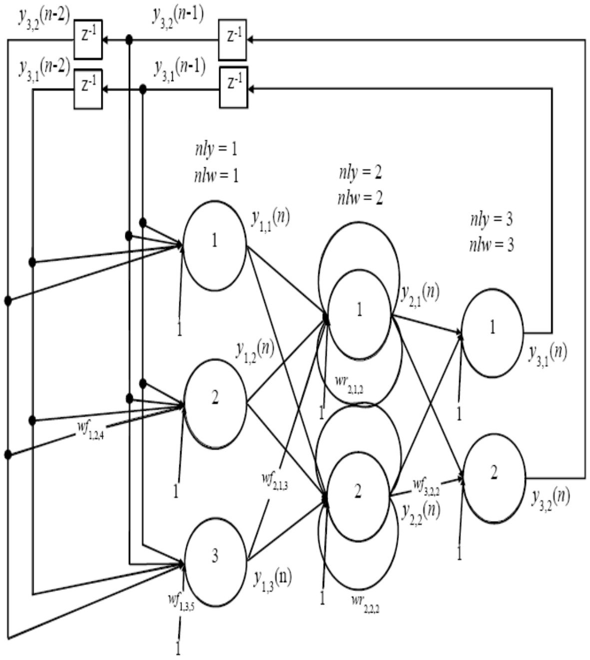


Fig.10. Recurrent Multilayer Perception Neural Network with structure (3×2$_R$ ×2(2))[14].

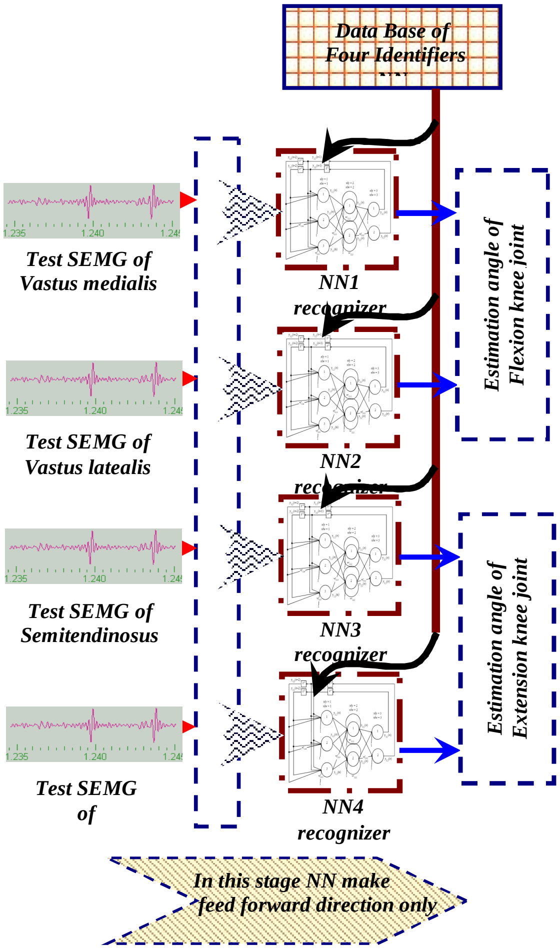


Fig.11. Estimation of knee joint angle.

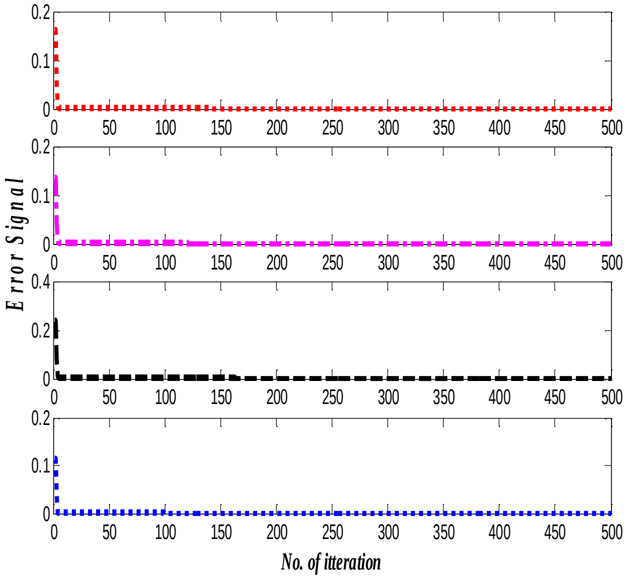


Fig. 12. Error signal for identification of four muscles SEMG signal

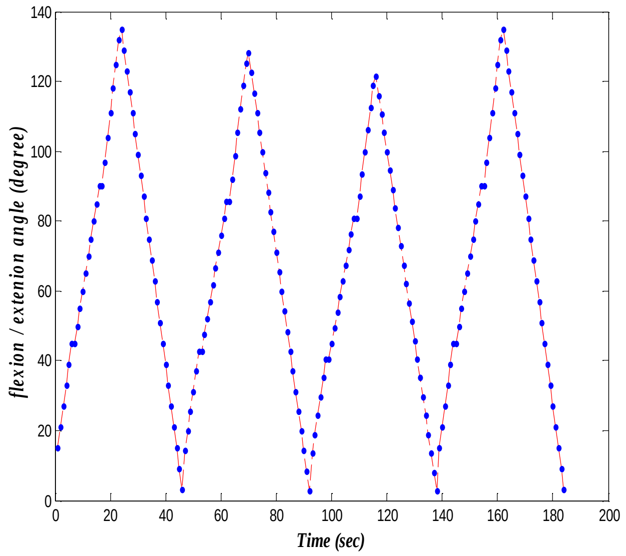


Fig.13. Estimation of knee joint angle with low speed movement.

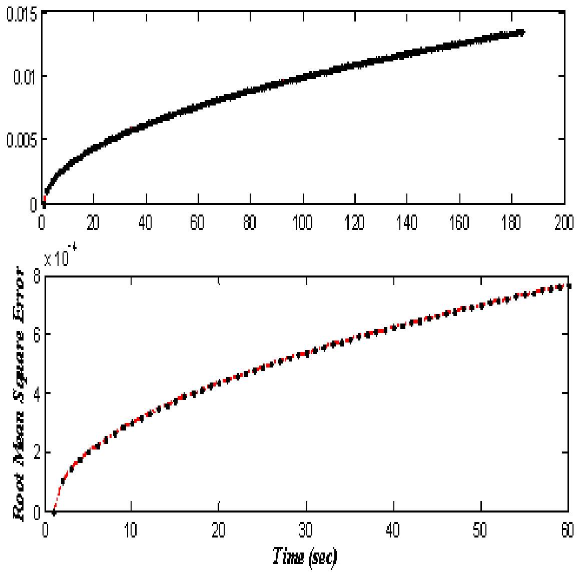


Fig.15. RMS values for two speed of human leg movement.

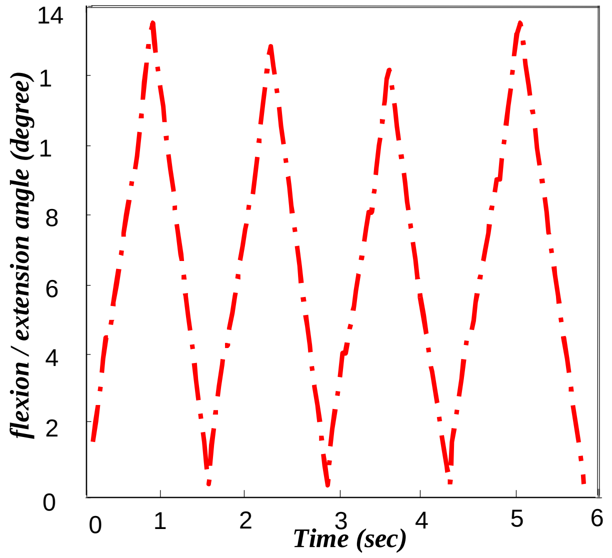


Fig.14. Estimation of knee joint angle with low speed movement.