New Developments in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics. Volume II: Applications

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Generalized net model of the upper limb in relaxed position

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Abstract

In a series of papers the Generalized Net models of the human body and its systems are described in general. In the present work, short remarks on GN modeling are given and a simplified GN model of the upper limb is constructed.

Keywords: generalized net, modeling, upper limb.

Abbreviations:

GN	Generalized nets
CVS	CardioVascular System
ENS	ENdocrine System
LMS	LyMphoid System
CNS	Central Nervous System
PNS	Peripheral Nervous System

1 Introduction

GN [1, 2] are extensions of Petri nets and their modifications. During the last 30 years, they have a lot of applications in medicine and biology. In [3] GN-models of human body and of the separate systems in the human body are described. One of the modeled by GN systems is the muscle-skeletal (see [4]). The present paper is the first one that is devoted to a GN-model of the upper limb. Here, it is in relaxed position. We represent the logical relations between separate elements of the musculoskeletal system of the upper limb and the participation of the nervous system. We will not consider the influence of CVS, ENS, LHS, the voluntary movements, and autonomic nervous system.

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2 Short anatomical description of the upper limb

The upper limb or upper extremity is a complex mechanism which includes many bones, joints and soft tissues allowing various movements in space. The musculoskeletal anatomy of the upper limb is particularly well suit to illustrate and illuminate the anatomical basis of function. In general the upper limb can be divided in shoulder girdle, arm, wrist and hand. The scapula, clavicle, sternum and the proximal part of the humerus comprise the shoulder girdle. The shoulder girdle is a complex of five joins: glenohumeral joint, acromioclavicular joint, sternoclavicular joint, scapulothoracic joint and suprahumeral [5] or subdeltoid joint [8]. The last 2 are not anatomical but physiological ("false") joints [8,19]. Arm or "brachium" is composed of 3 bones: distal part of the humerus, radius and ulnae. These bones form the elbow complex which includes: humeroradial, humeroulnar and superior radioulnar joints and also distal radioulnar articulation and the so - called "antebrachium" /composed of the radius and ulna/. The wrist is a terminal link of the upper limb. The wrist complex includes 3 joints: radiocarpal, distal radioulnar and midcarpal joints. The human hand is a multicomponent system not only with motor but also with sensory function. Bones and joints structures of the hand formed a mobile and stable segment [15]. There are: Carpometacarpal, metacarpophalangeal and interphalangeal joints. The skeleton of the upper limb is attached relatively loosely to the trunk. That relatively loose attachment maximizes upper limb mobility and flexibility (movement is possible in all 3 planes). The mobility and stability of the upper limb is provided by the large number of ligaments and muscles (see Table 1).

The proper functioning of the upper limb depends entirely on the intactness and coordination of the composed segments together with the major structures of the nervous system involved.

The nerve supply of the upper limb is provided by the brachial plexus and some branches of the cervical plexus (see Table 2). The brachial plexus is formed by the anterior rami of C5 to T1 (the posterior roots give innervation for the skin and muscle of the paravertebral area). The anterior rami supply the upper (C5-6), middle (C7), and lower(C8-T1) trunks. At the level of the superior border of the first rib, each trunk divides into an anterior and posterior division. The six divisions combine to form tree cords – lateral, posterior and medial. At the lower part of the axila the tree cords split in to the terminal branches which enter the arm and innervate the different segments. The major branches of the brachial plexus are: n.axilaris, n.musculocutaneus, n.ulnaris, n.radialis and n. medianus.

Table 1: Ligaments and muscles of the upper limb

Upper limb segments	**Ligaments**	**Muscles**
Shoulder girdle	lig.interclaviculare, lig.sternoclaviculare, lig.costoclaviculare, lig.coracohumerale, lig.coracoacromiale, lig.transversum scapulae super.et infer., lig.acromioclaviculare,lig.coraco claviculare	m.trapecius, m.latissimus dorsi, m. levator scapulae, m. rhomboideus, m. pectoralis major, m. pectoralis minor, m. subclavius, m. serratus anterior, m. coracobrachialis, m. deltoideus, m. supraspinatus, m. infraspinatus, m. teres minor, m. teres major and m. subscapularis.
Arm	lig.collaterale radiale, lig.collaterale ulnare, lig.anulare radii, Chorda obliqua, Membrana interossea antebrachii	m. brachialis, m. biceps brachii, m. brachioradialis, m. triceps brachii , m. anconeus, m. pronator teres, m. supinator, m. pronator quadratus, m. flexor carpi ulnaris, m. flexor carpi radialis, m. extensor carpi radialis longus, m. extensor carpi radialis brevis and m.extensor carpi ulnaris.
Wrist	lig.radiocarpeum palmare, lig.collaterale carpi radiale, lig.collaterale carpi ulnare, lig.radiocarpeum dorsale	m. extensor carpi ulnaris, m. exten-sor carpi radialis longus, m. exten-sor carpi radialis brevis, m. flexor carpi radialis, m. flexor carpi ulnaris, m. abductor pillicis longus and m. extensor pollicis brevis.
Hand	lig. carpi radiatum, lig. pisohamatum, lig.pisometacarpeum, lig.carpomatacarpeum palmare, ligg. metacarpea palmaria, ligg. metacarpea transversa profunda, ligg. collateralia, ligg. palmaria, ligg. metacarpea dorsalia, ligg. carpometacarpea dorsalia	m. extensor digitorum, m. extensor indicis, m. extensor digiti minimi, m. flexor digitorum profundus, m. flexor digitorum superfacialis, mm. lumbricalis, mm interossei, m. flexor digiti minimi, m. abductor digiti minimi, m. extensor pollicis longus, m. extensor pollicis brevis, m. abductor pollicis longus, m. flexor pollicis longus, m. flexor pollicis brevis, m. opponens pollicis, , m. abductor pollicis brevis, m. adductor pollicis and m. opponens digiti minimi.

Table 2: Innervation of the upper limb joints and muscles

Peripheral nerve	Innervated joint	Innervated muscle
n.aixllaris	Glenohumeral joint	m. Deltoideus, m. terres minor
n.suprascapularis	Glenohumeral joint, acromioclaviular joint,	m.infraspnatus,m.supraspnatus,
n.subclavius	Sternoclavicular joint,	m.subclavius, m.
n.dorsalis scapulae		m.levator scapulae, mm.romboidei
n.thoracalis longus		m.serratus anterior
nn.thoracales anteriores		m.pectoralis major et minor
nn. subscapulares		m.terres major, m.subscapularis
n.thoracodorsalis		m.latissimus dorsi
n.accesorius		m.trapezius
n.pectoralis lateralis et medialis	Glenohumeal joint,	m.pectoralis major et minor
n. musculocutaneus	Glenohumeral ljoint,Humeroradial joint	m.bicepsbrachii, m.brachilis, m.corracobrachialis
n. medianus	Elbow comlex, wrist and hand	m.pronator teres, m.pronator quadratus, m.flexor carpi radialis,m.flexor digitorum superfacialis,mm lumbricalis, m. flexor pollicis brevis, m.opponens pollicis, m.abductor policis brevis.
n. ulnaris	Elbow complex, wrist and hand	m.flexor carpi ulnaris, mm. interosiei, mm. lumbricalis, m.flexor digiti minimi, m.abductor digiti minimi, m.abductor pollicis, m.oponenc digiti minimi, m.flexor digitorum profundus.
n. radialis	Elbow complex, wrist and hand	m.brachioradialis, m.triceps bachii, m.anconeus, m.supinator, m.extenssor carpi radialis longus, m.extensor carpi radialis brevis,
n.interoseus	Elbow comlex and wrist	m.extensor digitorum, m. extensor indicis, m.extensor digiti minimi, m.extensor carpi ulnaris, m.extensor pillicis longus et brevis, m.abductor pillicis longus, m.

The PNS connects the brain and the spinal cord to the periphery and it includes the cranial nerves, the spinal nerves, the peripheral nerves and the peripheral extension of the autonomic nervous system [16]. Within peripheral nerves are motor and sensory fibers. The sensory fibers receive information from the receptors in muscles, tendons, joints and skin. Through these special structures providing information about muscle length, muscle tension, joint angles and indication of the distribution of forces at points of contact becomes possible (somatosensory receptors). That information is transmitted via afferent roots to the CNS. The processing and analysis of this information is subjective expression in the emergence of different senses. Its two submodalities are sense of stationary position (position sense) and sense of movement (kinesthetic sense) [13]. Apart from sensory, muscles are innervated by motor nerve fibers. Motor nerve fibers are called motoneurons and innervate the different parts of the muscle tissue. The relationship between a sensory and a motor neuron in the gray matter of the spinal brain is performed by an intermediate / inhibit / interneuron. The most routes from the higher centers of the CNS ended on these interneurons.

3 Short description of the "relaxed" (resting) position of the upper limb

For the purpose of the present paper we will describe shortly our concept on the "relaxed position" of the upper limb and inner-relationship between musculoskeletal and nervous systems.

In terms of the upright posture, which is a natural one (body position in space) in the human, the upper limbs are freely granted to the body as "volare" surface of the hand facing the body. Normally shoulders have a round contour due to prominence of the grater tuberosity beneath the deltoid muscle [9] and they are both with symmetrical height. (However many people have lower shoulder on the dominant side [10].) The shoulders are slightly protracted but relatively relaxed [6]. There is a minimal flexion in the elbows and the forearms (antebrachium) are in semi–pronated position. All of the five fingers are slightly flexed at all their joints. For the maintenance of this position there are not necessary to have voluntary movement or effort. In these conditions stability of the upper limb depends on static restraints (ligaments), muscular stabilizers and intra-articular forces. Ligaments and joint structures not only provide mechanical support but also provide sensory feedback information (from sensory receptors) that regulates involuntary muscular activation for joint positioning and stability. By the virtue of gravity and the weight of the upper extremity there is slight tension in the soft tissues (ligaments, tendons and muscles). The tension activates the different receptors and they send the information to the regulatory structures of the CNS. The spinal cord controls the positioning through the muscle activity and condition by means of a closed circuit. This type of regulation is through the formation of so- called “reflex arcs”.

4 A generalized net model of the upper limb

Here we represent a simplified GN-model of the upper limb in relaxed position.

The GN model (Fig. 1) has 4 transitions and 13 places with the following meaning.

- Transition Z_1 represents the function of the CNS.
- Transition Z_2 represents the function of the PNS (sensory and motor fibers of brachial plexus branches).
- Transition Z_3 represents the function of the striated muscles and tendons of the upper limb.
- Transition Z_4 represents the function of the joints and ligaments of the upper limb.

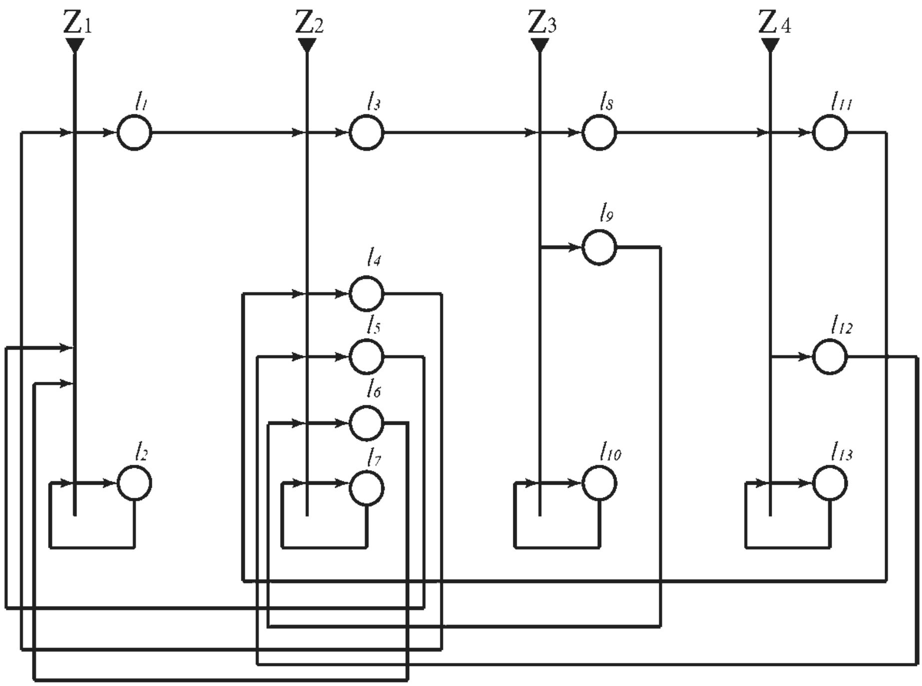

Figure 1: GN model of the upper limb

Each of these transitions contains a special place to collect and keep information about the current status of the respective structures which it represents, as follows.

- In place l_2 token α stays permanently and it collects information about the current status of the CNS.
- In place l_7 token β collects information about the current status of the PNS.
- In place l_{10} token μ collects information about the current status of the striated muscles and tendons.
- In place l_{13} token ν collects information about the current status of the joints and ligaments.

Tokens α, β, μ, ν that permanently stay, respectively, in these places obtain as current characteristic the corresponding information. At the time of duration of the GN-functioning, some of these tokens can split, generating new tokens, that will transfer in the net obtaining respective characteristics, and also in some moments they will unite with some of tokens α, β, μ, ν.

The four GN transitions have the following forms.

$$Z_1 = \langle \{l_2, l_4, l_5, l_6\}, \{l_1, l_2\}, r_1 \rangle,$$

where :

$$r_1 = \begin{array}{c|cc} & l_1 & l_2 \\ \hline l_2 & W_{2,1} & true \\ l_4 & false & true \\ l_5 & false & true \\ l_6 & false & true \end{array}$$

and $W_{2,1}$ = *"efferent impulses from the CNS are necessary for the maintenance and regulation of the muscles"*.

The tokens from all input places enter place l_2 and unite with token α that obtains the above mentioned characteristic. On the other hand, token α splits to two tokens, the same token α and α_1 that enters place l_1, when predicate $W_{2,1}$ has truth value "*true*". In the model, place l_1 corresponds to the kind of the efferent impulse from CNS.

$$Z_2 = \langle \{l_1, l_7, l_9, l_{11}, l_{12}\}, \{l_3, l_4, l_5, l_6, l_7\}, r_2 \rangle,$$

where:

$r_2 =$	l_3	l_4	l_5	l_6	l_7
l_1	*false*	*false*	*false*	*false*	*true*
l_7	$W_{7,3}$	*true*	*true*	*true*	*true*
l_9	*false*	*false*	*false*	*false*	*true*
l_{11}	*false*	*false*	*false*	*false*	*true*
l_{12}	*false*	*false*	*false*	*false*	*true*

and $W_{7,3}$ = *"efferent impulse from CNS was transmitted via motor fibers of the PNS branches to the muscles of the upper limb"*

The tokens from all input places enter place l_7 and unite with token β that obtains the above mentioned characteristic. On the other hand token β splits to five tokens, the same token β and tokens β_1, β_2, β_3, β_4 that enter respectively in places l_3, l_4, l_5, l_6. When predicate $W_{7,3}$ has truth value *"true"*, a token enters place l_3.

Token in place l_3 obtains characteristics

"*efferent impulse to the muscles of the upper limb*".

Token in place l_4 enters with characteristics

"afferent (sensory) impulse from the joints of the upper limb".

Token in place l_5 enters with characteristics

"afferent (sensory) impulse from the ligaments of the upper limb".

Token in place l_6 enters with characteristics

"afferent (sensory) impulse from intra and extrafusal muscle fibers".

$$Z_3 = <\{l_3, l_{10}\}, \{l_8, l_9, l_{10}\}, r_3>,$$

where:

$r_3 =$	l_8	l_9	l_{10}
l_3	*false*	*false*	*true*
l_{10}	$W_{10,8}$	*true*	*true*

and $W_{10,8}$ = *"there is involuntary muscular activation".*

The tokens from all input places enter place l_{10} and unite with token μ that obtains the above mentioned characteristic. On the other hand, token μ splits to three tokens, the same token μ and tokens μ_1, μ_2 that enter respectively in places l_8, l_9.

When predicate $W_{10,8}$ has truth value *"true"*, a token enters place l_8. There it obtains characteristics *"influence of the muscular activation on the upper limbs joints and ligaments (joints positions)".*

Place l_9 corresponds to the sensory receptors in muscle fibers of upper limb muscles.

$$Z_4 = <\{l_8, l_{13}\}, \{l_{11}, l_{12}, l_{13}\}, r_4>,$$

where:

$$r_4 = \begin{array}{c|ccc} & l_{11} & l_{12} & l_{13} \\ \hline l_8 & false & false & true \\ l_{13} & true & true & true \end{array}$$

The tokens from the two input places enter place l_{13} and unite with token ν that obtains the above mentioned characteristic. On the other hand, token ν splits to three tokens: the same token ν and tokens ν_1, ν_2 that enter respectively in places l_{11}, l_{12}.

Token in place l_{11} obtains characteristics

"the position of individual joints of upper limb segments in space".

Place l_{12} corresponds to the sensory receptors in ligaments and joints of the upper limb.

5 Conclusion

GN model constructed in that way is the first step to building a detailed GN-model describing the overall function of the upper limb. In future papers we will construct GN-models describing the relations among the upper limb structures and the rest body systems. The future models will include the presence of voluntary movements, different types of pathology and rehabilitation treatments. Though our present work was concentrated to the modeling of the upper limb, the methodology and tools can be applied to the modeling of any other part or the whole body.

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The papers presented in this Volume 2 constitute a collection of contributions, both of a foundational and applied type, by both well-known experts and young researchers in various fields of broadly perceived intelligent systems.
It may be viewed as a result of fruitful discussions held during the Tenth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2011) organized in Warsaw on September 30, 2011 by the Systems Research Institute, Polish Academy of Sciences, in Warsaw, Poland, Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences in Sofia, Bulgaria, and WIT - Warsaw School of Information Technology in Warsaw, Poland, and co-organized by: the Matej Bel University, Banska Bystrica, Slovakia, Universidad Publica de Navarra, Pamplona, Spain, Universidade de Tras-Os-Montes e Alto Douro, Vila Real, Portugal, and the University of Westminster, Harrow, UK:

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The consecutive International Workshops on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGNs) have been meant to provide a forum for the presentation of new results and for scientific discussion on new developments in foundations and applications of intuitionistic fuzzy sets and generalized nets pioneered by Professor Krassimir T. Atanassov. Other topics related to broadly perceived representation and processing of uncertain and imprecise information and intelligent systems have also been included. The Tenth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2011) is a continuation of this undertaking, and provides many new ideas and results in the areas concerned.

We hope that a collection of main contributions presented at the Workshop, completed with many papers by leading experts who have not been able to participate, will provide a source of much needed information on recent trends in the topics considered.

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