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CONTENTS

A COGNITIVE APPROACH TO NEURAL NETWORK MODEL BASED ON THE COMMUNICATION SYSTEM BY AN INFORMATION CRITERIA

A. Horiushkina, S. Seker, and U. Korkmaz

Abstract— In this paper presents the structural analogy between the artificial neural net (ANN) architecture and communication system principles. Thus, a feed forward auto-associative ANN is assumed like a communication system and the channel capacity is defined as an information measure related to the number of hidden nodes which are in one hidden layer of the neural net. Here, the channel capacity formula which is given for the communication channel is represented as information a criterion that is connected with Shannon's entropy. Hence it is defined as information capacity under the interpretation of cognitive capacity and set theory approach is also used to define the ANN in manner of cognitive system.

***Keywords* —** *Neural Nets, Communication Channel, Learning System, Shannon's Entropy, Cognitive Systems.*

1. INTRODUCTION

THE rapid development of technology over the past decade in the neural network topology area, has determined that one of the most important problems here is the determination of number of hidden nodes and layers in the neural topology. It is shown that there are a lot of studies in the theoretical and application area [1-3]. As studies show, at present time this is still an open problem, but its importance is reduced due to the development of hardware technologies, and then the time for computing data is reduced. However, technology which are using today goes to different fields for example quantum computing and artificial cognitive system. Especially, the cognitive system engineering applications will be point of focus at next generations of the technology. The cognitive system consists of: Sensing, learning, communication, logic and decision making. In this sense, a neural network can be considered as learning system which is consistent with the data, and also it can be interpreted from this framework and it is presented as follows. This study defines the artificial neural networks (ANN) as a cognitive structure and its hidden layer is described as communication channel and hence, interpreted as an information processor unit. In this manner ANN's cognitive interpretation is given.

2. ARTIFICAL NEURAL NETWORK (ANN) AND A BASIC COMMUNICATION SYSTEM

An artificial Neural Network can be related with the Communication system as below.

2.1. The Topology of ANN

An ANN-topology can be defined as parallel massively distributed system [4,5] by the following figure 1:

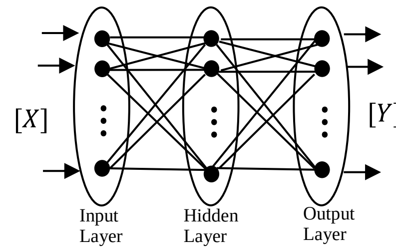

Fig.1. An auto associative neurol network

As indicated in figure 1 it is in the form of auto-associative, namely its input nodes number equals to output nodes number. Where, the input and output matrices are respectively defined with the same dimensions as below:

$$X \triangleq \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1M} \\ \vdots & \vdots & & \vdots \\ x_{N1} & x_{N2} & \cdots & x_{NM} \end{bmatrix}_{N\times M}$$

and

$$Y \triangleq \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1M} \\ \vdots & \vdots & & \vdots \\ y_{N1} & y_{N2} & \cdots & y_{NM} \end{bmatrix}_{N\times M}$$

Here the neural topology is accepted with only one hidden layer to get the simplicity and the number of the hidden nodes taken place in the hidden layer is considered as an unknown parameter (variable). This unknown parameter, which is the number of hidden nodes, is represented as channel capacity of the Communication system.

2.2. Communication Channel

Basic structure of a communication system is highly similar with the neural topology [6] as shown in Figure 1 and 2,

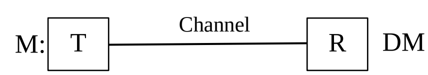

Fig. 2. A Communication System.

where

M: Modulator, T: Transmitter, R: Receiver and DM: Demodulator;

The communication channel can be represented in the form of wire, air, radio link etc.

The channel capacity is described by the Shannon's formula as follows

$$C_{max} = Blog_2[1 + SNR] \tag{1}$$

Here,

C_{max}: Maximum channel capacity and $[C_{max}]$: $bit/_s$

B: Band-width of the channel,

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SNR: Signal to Noise Ratio.

3. SHANNON'S INFORMATION AND ANN-TOPOLOGY

Analysis of the literature [1-3] showed that C. Shannon was defined the channel capacity by a mathematical method as indicated in Eq. (1). The Shannon's approach can be generated from the Boltzmann's entropy [7] approach as shown in

$$H = k\ln(W). \tag{2}$$

Here W is the number of macroscopic states in the system while indicating the constant k is Boltzmann's constant. C. Shannon developed this concept in the probabilistic manner and it was given as written below:

$$H = -\sum_{i=1}^{N} p_i\, log_2\,(p_i). \tag{3}$$

Where, N is number of the possible states and p_i is (i=1, 2,…, N) also probability value which is connected with each case (state).

3.1. ANN Topology and Channel Capacity

An auto-associative neural network topology is considered as shown in the figure 1, it is input-output pairs has same dimensions as vector sizes, in terms of the number of training patterns, the following assumptions is taken into account:

Assumption:

The input matrix can be defined as a square matrix

$$\underset{\sim}{I} \triangleq \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1N} \\ \vdots & \vdots & & \vdots \\ x_{N1} & x_{N2} & \cdots & x_{NN} \end{bmatrix}_{N\times N}$$

The probability of each of elements is appeared in the matrix $\underset{\sim}{I}$ is defined with equally likelihood cases:

$$p_i \triangleq p(x_i) = \frac{1}{N}$$

Hence, the Shannon's formula which is given by equation (1) can be written as

$$H = -\sum_{i=1}^{N} p_i\, log_2\,(p_i) = -N\left(\frac{1}{N} log_2\left(\frac{1}{N}\right)\right),$$

$$H = -N log_2\left(\frac{1}{N}\right) = log_2(N). \tag{4}$$

And it is approximated to number of hidden nodes M, using proportionality:

$$M \propto H = log_2\,(N) \tag{5}$$

Therefore, this proportionality, the factor J used in Equation (6) and it is an integer.

As a result of this calculation, the equation (1) that is Shannon's channel capacity can be extended to neural topology in the form of

$$M = J\, log_2\,(N). \tag{6}$$

In this formula, N is a number of states or number of elements of input vector. Factor J is also proportionality constant and M is also number of the hidden nodes in the one hidden layer [1,2]. This is also the equality of channel capacity which is defined in the Communication Systems. Hence, it is described as an information amount (Inf.) depending on the topology [1, 2,8].

4. DEFINITION OF A COGNITINE SYSTEM

A cognitive system is related with cognition and the cognition is also a combination of the Perception, Attention, Memory and Intelligent. In general manner, the cognitive system is defined with the other abilities between the perception and action. These are realized on the environment by means of the feedback mechanism as shown in the following figure 3 [9].

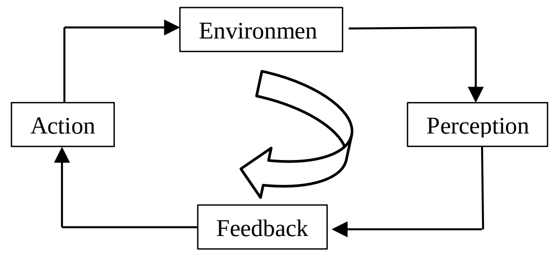

Fig. 3. Cognitive System: Dynamical Perception-action cycle.

This perceptron-action cycle gets to provide the information about the environment. Hence, the information is gained by going on one cycle to the next. This is a Cognitive Dynamical System.

In this cycle, the action is an executive subsystem and it plays role of the memory received from the environment. In this manner, it is presented as an executive memory that learns from actions on the environment. From another side, the perceptual memory is connected with the learning from observations of the environment. More general form of the memory system is "working memory" which provides the means between the perceptual memory and executive memory. The whole memory system provides the prediction of actions taken by the system while learning from the system [10, 11].

Attention is another function of the cognitive system and it is a structure which is built on the perception and memory system. In this manner it is a subsystem of the perception and memory. Intelligence is a basic function of cognitive system and it is based upon the perception, memory and attention as an upper system of 4-functions. These 4-functions of the cognition mechanism provide the decision making to do the intelligent choices under the uncertainties. In this sense a cognitive system is defined by the following Venn-diagram:

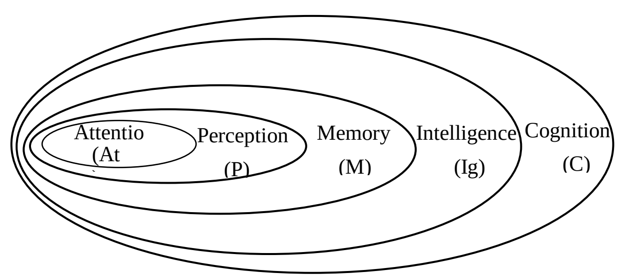

Fig. 4. Venn-diagram of cognitive system.

Where *At*: Attention and $At \subset P \subset M \subset Ig \subset C$

$$M \supset (At \cup P) \quad (7)$$
$$Ig \supset (At \cup P \cup M) \quad (8)$$
$$C \supset (At \cup P \cup M \cup Ig) \quad (9)$$

5. CONCLUDING REMARKS AND COGNITIVE INTERPRETATION

The comparisons on the cognitive system (COGS) and artificial Neural Network (ANN) can be representing as shows bellow:

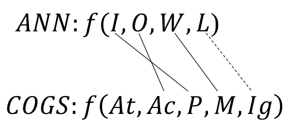

Fig. 5. The displaying between ANN and COGS.

Here ANN is a function of I: Input; O: Output; W: Weight and L: Learning as well as architecture for COGS it becomes At: Attention; Ac: Action; P: Perceptron; M: Memory and Ig: Intelligence.

Thus, ANN provides the one-to-one relationship with COGS. But, the connection between L and Ig is dashed line because of the connection in weak sense because Ig is not identity to the learning. However, using the communication channel capacity approach, it is connected with the number of the hidden nodes in a one-hidden layer and hence, this units play role of the Information processor and its capacity. Therefore, it is shown as below:

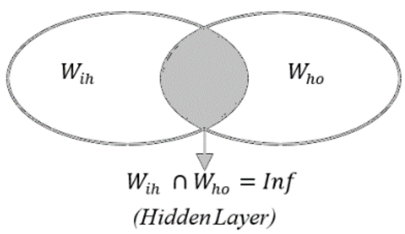

Fig. 6. The Venn diagram for getting the information (Inf) in the hidden layer.

As a result the functional structure of the trained ANN can be given as $ANN^*: f(I, O, W^*, L, Inf)$; *: after the training.

Then, ANN^* becomes a cognitive system under the consideration of following comparison:

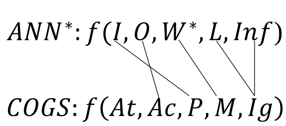

Fig. 7. The displaying between ANN* and COGS.

Finally, the concept of the cognition can be attributed to the ANN-structure by means of the information capacity of the hidden nodes in ANN.

5.1. Displaying Compositions Between ANN and COGS Sets

In set theory, there are three types of the relationships. These are respectively injective, surjective and bijective. If the displaying considered as shown in figures (5) and (7), they can be represented in the form of the combinations.

$$Displaying : ANN \rightarrow ANN^* \rightarrow COGS$$

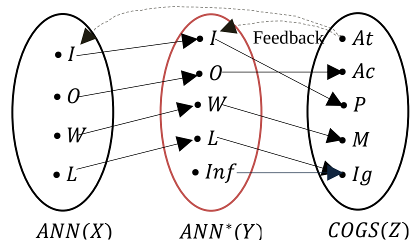

Fig. 8. The injective compositions of Displaying.

This is injective combination: ANN^* need not be injective, in this manner the relationship between ANN and $COGS$ is one-to-one relation with the reason of injective property. However, the element At, which shows the attention function, in the $COGS$ is not connected with any element in ANN or ANN^*. However, this function can be related with the input element of the ANN (or ANN^*). This provides a feedback connection of the cognitive system. To get this feedback, the order of the displaying is changed as follows:

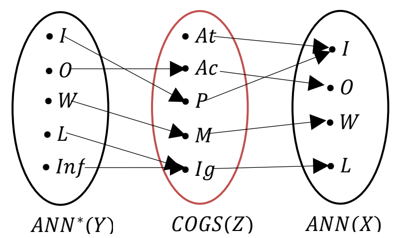

Fig. 9. The surjective compositions of Displaying.

Here the entire relationship is in the form of surjective composition. It means that if there is any relationship in a next way $f: Y \rightarrow Z$ it can be shown by the $f: Z \rightarrow Y$, then it can be interpreted as ANN^* also becomes Cognitive system while a Cognitive system is displaying to a ANN system. Hence, the cognitive systems can be interpreted by means of the ANN [12].

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BIOGRAPHIES

Alla Horiushkina was born in Ukraine. She received the PhD degree in Computer science from National Technical univerity “Kharkov Politechnical Institute” (NTU “KhPI”) in 2016. She became associate professor in 2017 at the same university. Her current research interests are Signal Processing, Computational Intelligence, and Computational Cognition.

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AN ARTIFICIAL NEURO DETECTOR AND ITS COGNITIVE INTERPRETATION FOR ENGINEERING SYSTEMS

D. Bayram Kara, and S. Şeker

Abstract— In this paper the definition for an artificial Neuro-Detector and its working principles are given conceptually. The methodology to be followed is simply introduced. Then some examples and suggestions to employ Neuro-detection in industry are presented through to the real world problems. The cognition run through a Neuro-Detector is discussed in terms of defining its cognitive abilities. Then the analogies between a cognitive system and an Artificial Neural Network based detector system are unfolded.

Keywords— *Detector, Auto Associative, Neural Network, Cognition*

1. INTRODUCTION

THE Neuro - Detector is a concept which is defined inspiring the human brain detection and perception ability. In order to detect an abnormal feature, human brain should first learn the normal condition. Then the abnormal condition can be identified through the comparison of the learned normal condition and noticed the abnormal one. The detected and identified abnormal condition consists of an alternative condition which should be perceived as a diverse state. To model the human brain detection and perception ability, a structure which may learn and compare is needed.

The neural networks are the best candidate for such task. Neural networks are very common mathematical tools which are used for decades to model nonlinear relationships, patterns and mappings between input output pairs. Their basic building blocks are neurons; modelled by the weighted sums of inputs, which are calculated as a function of a nonlinear activation function at output. There is an input layer which receives the intake information of the system. This information is weighted properly by the help of error propagation algorithms. The weighted inputs are summed and applied to the hidden layer whose task is the application of a nonlinear function defined for the problem. Then the output layer maps to the hidden layer. The learning ability of the network can alter due to the structure and construction, namely topology. The topology is drawn by the type of network, the sizes of input output and hidden layers, the error propagation algorithms, etc. The topology should be defined considering the nature of the problem [1-7].

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2. BASIC CONCEPTS FOR NEURO-DETECTOR

The Neuro - Detectors are artificial neural network (ANN) based structures which can be used to detect a different state of the system. It can be either a faulty operation or a condition which is located out bounds of the definition space. For such application a specific type of network, named as Auto-Associative Neural Network (AANN) is required. AANN are feedforward structures which defines a mapping between input output pairs using back propagation algorithm. This type of network compresses the information, which is transferred from the inputs, at the hidden layer. And the input and output layers have the same size while the hidden layer has a smaller dimension. By this point of view, it behaves as a bottleneck for the flow of the transported information [1]. A simplified representation is shown in Figure 1.

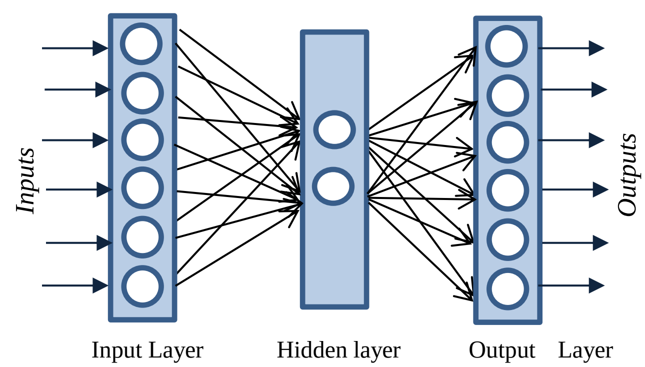

Fig.1. Simplified representation for Auto Associative Neural Network.

They can be used for the classification of complex systems, discovering patterns [2] feature extraction and dimensionality reduction in one or two dimensional systems [3, 4]. For engineering applications, it can be employed for tuning and ameliorating control, decision making, fault detection and isolation (FDI) purposes [3]. As the main FDI works, AANN can be used for sensor validation [5] or as a fault compensator for drifted sensors [6]. It can be supported by some other preprocessing operation to enhance the capability of learning such as linear prediction analysis [7] or nonlinear princaple component analysis [3].

In all of these studies, the data collected for a determined operation condition of a system is applied to an AANN and the network is trained by the data having the same trait. Speaking of the trait, the data is defined by its specific and distinctive property related to the problem. For FDI problems spectral characteristics are used commonly. The spectral representation of the system is the natural indicative for the condition of the system. In other words, the determined case's spectral representation is used to train the network. By this way, the network succeeds to recognize the defined operation. If any condition which is spectrally disparate is encountered, the network is expected to raise an error. For example, when the network is trained with any spectral representation of a healthy operation, then it will warn us with an error when a faulty operation is confronted.

3. METHODOLOGICAL BACKGROUND OF THE NEURO-DETECTOR APPLICATIONS

In order to provide a consistent Neuro - Detector application, there are some important points to be considered. For this purpose, a flow diagram given in Figure 2. First, the data should be collected representing a reference state of the system. Then the chosen form of the spectral representation of this condition are calculated. The AANN is trained by the normalized representation of this reference state. By using normalization, the characteristic of the spectral behaviour is evaluated instead of amplitude information. After a successful training procedure, the output of the network is compared with the upcoming case. If the error signal is higher than a defined threshold, which is close to the training and validation error of the network, then the error alarm can be set. Thus, the detection is accomplished using the AANN driven by the spectral properties of the collected signal. Then through the obtained error signal, the fault identification can be achieved.

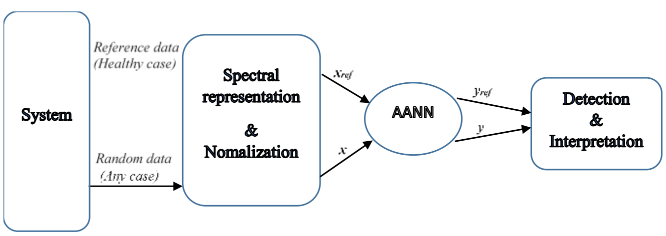

Figure 2. Flow diagram for Neuro - Detector.

4. INDUSTRIAL APPLICATIONS FOR NEURO DETECTOR

The algorithm for the detection through an AANN is suggested for industrial processes in the literature. As an example, in [8] the vibration signals of an electric motor collected for healthy operation are split to blocks and Power Spectral Densities (PSD) of the blocks are calculated. An AANN is trained through these PSDs, aiming to learn the healthy operation of the system. While the system receives PSD of a faulty operation, it is measured an error cumulated at the high frequency bands. This kind of characteristics associates with the bearing aging for electric motor.

Similarly, in [9] a Neuro - Detector is used for the identification of electric motor bearing problem. However, this time it is claimed that low frequency bands also carry hints about the bearing aging. The vibration signals collected from healthy and faulty cases of the machine are observed through the Multi Resolution Wavelet Analysis to filter specific bands of the spectrum. The AANN is trained with the low frequency band of the healthy data spectrum. The network successfully detects the bearing fault when the faulty operation is met. By the interpretation of extracted frequencies identification of specific faults are accomplished for the specific parts of the bearing.

In [10] a Neuro - Detector is designed to detect the insulation failure through the coherence analysis between current and vibration signals. The network is trained with healthy case coherence function. When the coherences of faulty case from various sensors are applied to the detector, it has successfully determined specific frequencies which associates with the insulation failure. Then as well, in [11] the coherence analysis between current and vibration signals is used to detect bearing fault. A similar procedure is adopted in this paper too.

5. CYBERNATIC APPROACH TO NEURO–DETECTOR

Since the automata and ANN are described based on finite sets, any system including the perception and learning process can be assumed as an automaton [12]. On the application, automata has the active interaction with human-machine and community. On the other hand, ANNs can be interpreted as the processing units providing the model of a complex system such any organization regarding human-machine cooperation [8].

Similar to an ANN, automata can be defined through 5 quantities as seen in (1). These are simply input, output, internal states and state functions.

$$A = (I, O, W, \Omega, \Psi) \quad (1)$$

where, *I*: a finite input set; *O*: a finite output set; *W*: a finite set of the internal states, Ω and Ψ are next state function and next output function respectively. While the Ω and Ψ can be defined mathematically as in (2).

$$\begin{aligned} \Omega &: W \times I \rightarrow W \\ \Psi &: W \times I \rightarrow O \end{aligned} \quad (2)$$

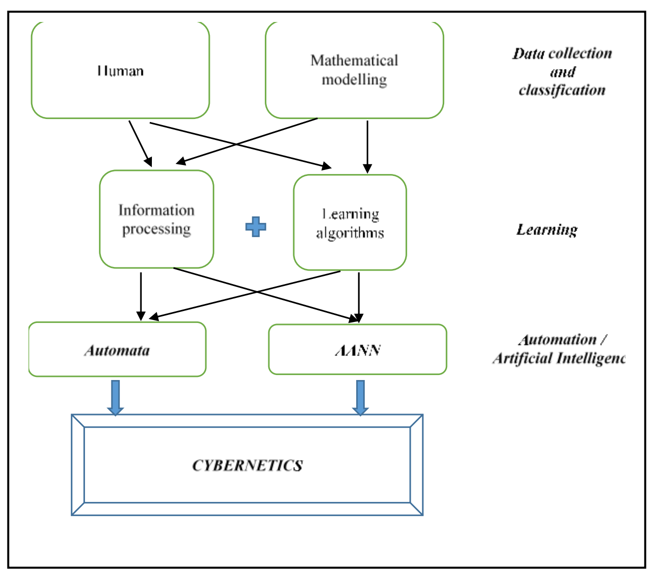

Figure 3. The information flow for a cybernetic system

For a case that input output pair number is equal, the automata and AANN resemble each other. The W associates the epochs while the Ω and Ψ represents the learning algorithm such as back propagation algorithm.

A simplified representation for the information flow of AANN and Automata is given in Figure 3. The data collection and its evaluation is executed by human effort. Then the information processing and its learning are done by the machine. The decision and built of an intelligence is succeeded by either automata or AANN. By this point of view these three stages can be considered as the interaction of Man, Machine and Cybernetic system.

6. A Cognitive approach to Neuro-Detector

A cognitive system collects information from the environment wisely by making attention and using sensing abilities to sort them to an order of importance. It learns the collected information and stores it in the memory. The capacity of learning and storing the information composes the intelligence. The integration of these skills can be interpreted as Information Processing Unit (INF-PU) of the conscious. The learned and stored information constitutes knowledge which is the precursor of decision making and taking action. Then, the actions and decisions are used for scanning of the environment again to create a new information processing operation. This flow could be called as Cognitive System Cycle (CSC).
On the other hand, artificial Neuro - Detector follows a similar flow to CSC. The sensor information is collected from the system and it is preprocessed through a trait (such as spectrum or amplitude, etc.). Then the ANN - based learning and error calculation for FDI purposes is performed. If a reasonable error is obtained, then the identification should be made. The action is developed for the identified fault.
By this point of view, as seen in Figure 4, an ANN – based Neuro - Detector can be accepted like a cognitive system in a weak sense. Pure cognitive system uses the intelligence as a function of conscious whereas the artificial one is connected with the computational intelligence.

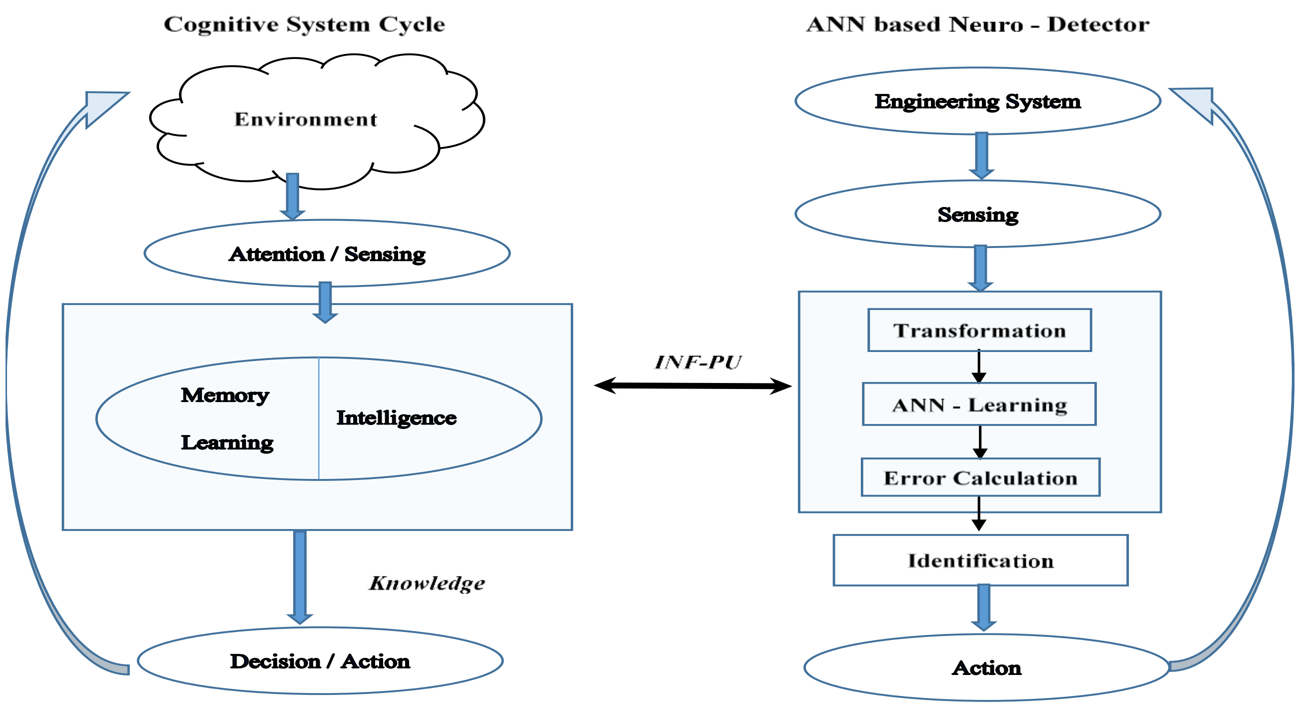

Fig.4. The analogy between a CSC and ANN based Neuro - Detector

7. Conclusions

In this study the basics for AAN - based detector are presented. A special type of network named as Auto Associative Neural Network to build a Neuro-Detector is introduced with its topological properties. The industrial applications of Neuro-Detector powered by AANN are listed. Thereafter the analogy between a cognitive system and a Neuro-Detector are highlighted.
It can be concluded that the artificial neural network shows similarities with an automata and also AAN - based systems can be accepted as the cognitive systems in a weak sense. Here, the weakness is because of the concept of consciousness. The conscious is a basic feature of a living system and it can be interpreted as a natural intelligence. However, today's technology is built upon computational intelligence rather than natural one.

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Biographies

Duygu Bayram Kara received the BSc., MSc and PhD degrees from the Electrical and Electronics Faculty of Istanbul Technical University (ITU) in 2006, 2009 and 2015, respectively. She worked as research assistant in Electrical Engineering Department at ITU between 2007-2015. She has employed by the same department as Assistant Professor since February 2016. She worked at Nuclear Engineering Department, University of Tennessee, Knoxville-USA in 2013, on in-situ condition monitoring using electrical signature analysis, as a visitor researcher. Her research areas are condition monitoring, fault detection, signal processing, soft computing electric machinery and harmonic concept. She actively provides technical consultancy service on electric motor projects for the industry.

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LIGHT, HUMAN COGNITION AND LIGHTING DESIGN

L. Erdem Atılgan

Abstract— This paper aims at looking at the effects of light on cognitive responses through elaborating the current knowledge on the ipRGC photoreceptor cells and how they influence the circadian rhythm as well as cognitive processes of the body throughout the day. Experimental studies in the literature are discussed and the lighting design approach corresponding to the non-visual effects of light on human cognition, the human centric lighting approach is explained.

Keywords— *Light, Vision, Lighting, ipRGC, circadian rhythm, Human centric lighting*

1. INTRODUCTION

Among the five senses the human body has been equipped with for sensory inputs, vision appears to be the most dominant when it comes to observing the world around us. Without light, the human eye can not perform the task of seeing. When light is present, the eye uses the photoreceptor cells in the retina, namely rod and cone cells, to transform the light energy into elecrical signals which the brain can process and form a visual understanding of the objects and the environment around us.

Until 2002, scientists thought that the process of seeing was only dependent upon the rod and cone types of photoreceptor cells. However, Berson and his colleagues brought another type of photoreceptor cell, namely the intrinsic photoreceptive retinal ganglion cell (ipRGC) into light through blocking the synaptic input from rod and cone cells in the rat retina and following the synapses from retinal ganglion cells when subjected to light [1]. These special cells detect the ambient luminous intensity as well as the spectrum of light and according to this detection process, regulate the release of melatonin from the pineal gland through which the circadian rhythm is adjusted. Thus, the eye is responsible for two different types of responses: visual and non-visual. The literature refers to this distinction as image-forming (IF) and non image-forming (NIF) processes as well [2]. There are numerous studies in the literature which show that lighting can manipulate the physiological arousal, neural activity, hormone production, and subjective alertness of human beings, along with cognitive processes such as attention, inhibitory control and working memory [3]. This paper aims at taking a look at the effects of light on human beings on these different levels and elaborate the recent lighting design approaches using these effects as their point of origin, such as human centric lighting design.

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2. LIGHT, VISUAL AND NON VISUAL RESPONSES

Among electromagnetic waves, light constitutes a small range falling between 380 nm and 800 nm. The previously mentioned cone and rod cells are responsible for photopic (daytime) vision corresponding to luminance values approximately above 10 cd/m^2 and scotopic (night time) vision corresponding to luminances approximately below 0.001 cd/m^2, respectively. In between these two luminance values, mesopic vision, in which both cone and rod cells are active, takes place. In order to quantifty the radiation affecting human visual response, the The Commission Internationale de l'Eclairage (CIE) luminous efficiency functions are utilized. The CIE has defined two luminous efficiency functions quantifying human visual response according to wavelength, V(λ) for photopic vision and V'(λ) for scotopic vision. Fig. 1 shows the CIE Standard 2° Photopic and Scotopic Luminous Efficiency Functions of Wavelength plotted using the values given in the IES Lighting Handbook [4].

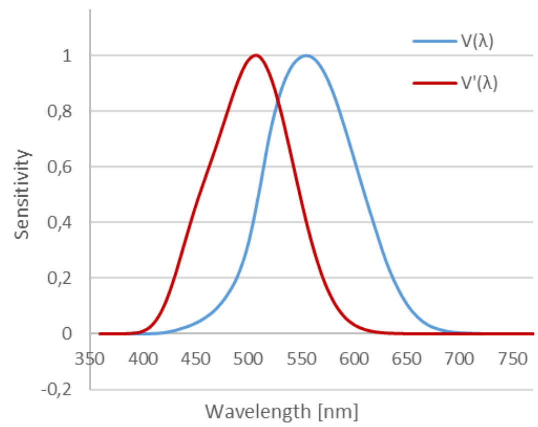

Fig.1. CIE Standard 2° Photopic and Scotopic Luminous Efficiency Functions

The CIE photosensitivity curve shows that for daytime vision, the maximum sensitivity of the human eye is at 555 nm, corresponding to green light on the electromagnetic spectrum. This peak sensitivity, however, changes for non-visual responses; research made on humans, macaque monkeys and rodents show that the most effective wavelength range is between 459 and 485 nm, corresponding to blue light instead of green. There are also studies showing that the change of color from green to blue affects the aforementioned physiological attributes, such as melatonin rhythm and secretion, body temperature, heart rate elevation, sleepiness reduction and improvement of alertness.

The non-visual responses to light are strongly related to the photopigment melanopsin, expressed by ipRGCs, whose maximum sensitivity is approximately at 480 nm. ipRGCs prevail throughout the retina in low densities and currently appear to be the sole connection of light and non-visual responses, however they receive time-varying information from rod and cone cells throughout the day as well [5].

2.1 The Circadian Rythm

The Circadian rhythm is a result of the earth rotating around its axis and exposing all living creatures to daylight and darkness in a 24-hour period. The name comes from the Latin words circa which means about and dies which means day. Throughout the day, the body temperature, hormone secretions, sleep orders, cognitive performance and numerous physiological attributes are affected by this process. The Suprachiasmatic Nucleus (SCN) situated in the mammal brain is responsible for controlling the circadian rhythm. In order to keep the SCN up to the 24-hour period, sensory inputs, mainly light is necessary, The literature refers to this phenomenon as "photoentrainment" [6, 7]. Thus light acts as an entrainment tool for the body to set its biological clock to the Earth's clock [2, 8]. Human experiences such as jet lag, where traveling to different time zones affect the sleeping behaviors are results of the shift in the circadian rhythm. In such a case, sleep deprivation results in fatigue and bad moods as well, thus these types of examples show that in addition to human behavior, human emotional state is also influenced by the circadian rhythm.

2.2 Cognitive Effects – Experimental Studies in the Literature

Visual tasks are formed of visual, cognitive and motor mechanisms [9]. The literature shows that the concepts explained in this paper so far have a strong influence on non-visual functions such as the amelioration of alertness and performance on a number of cognitive tasks and that brain function and cognition are directly manipulated through lighting and its properties. According to several studies, light exposure can affect hormone secretion, heart rate, sleep propensity, alertness, body temperature, retinal neurophysiology, pupillary constriction and gene expression [7, 8, 10-13]. Cognitive processes such as attention, executive functions and memory are strongly affected by the circadian rhythm in human beings. There exists a strong fall in cognitive performance at night time with a strong rise at day time. There is also research showing that light can directly affect cognitive performance through exposure both at night and day for actions such as visual search, digit recall, serial addition-subtraction, two-column addition, logical reasoning task, letter cancellation task and simple reaction time tasks [5]. For instance, 94 white collar office workers who were exposed to blue-enriched white light for four weeks during daytime showed improvements in terms of subjective alertness, performance and decreased evening fatigue as well as night-time sleep quality [13]. A similar study by Milles et al. showed that high values of correlated color temperature (CCT) could improve the wellbeing and productivity of occupants in a corporate environment [14]. Both studies used 17000 K CCT light sources and on the lighting design point of view, the visual comfort created through such high levels of CCT is a question mark. However, the study by Chellappa et al. in which a comparison of warm CCTs to 6500 K showed that the latter cold light color created a greater melatonin supression and ameliorated subjective alertness, well-being and visual comfort [15].

In other studies, neuroimaging, namely Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI) techniques were used to investigate the influence of light exposure during daytime on attributes such as auditory perception, attention, executive function, working memory and updating [16-18]. An important finding was that these techniques were able to detect the effect of light on active cognitive brain activity. Another finding was that light triggered many different subcortical and cortical regions in the brain, responsible for different cognitive attributes. Using different wavelength, thus different colored light in the experimental studies, it was also seen that blue light of wavelength approximately 460 nm provided better performance results compared to green light of wavelength approximately 550 nm when a simple vigilance reaction time task was carried out. In a more complex task, the fMRI results showed that blue light (appr. 480 nm) ameliorated brain responses compared to green (appr. 550 nm) and violet (appr. 430 nm). The amount of light, which is related to the duration of exposure and also luminous intensity was among the findings which were found to be related to the time course as well as which region of the brain was affected. The studies clearly show that light exposure, depending on its duration and amount of photons as well as its wavelength has strong influences on cognitive brain responses [5].

3. LIGHTING DESIGN APPLICATIONS

While the visual and non-visual effects of light on human beings is a subject that continuously evolves as scientists receive more findings from their studies on the human body, what delivers light to humans is lighting. Therefore, the correct design of lighting is of upmost importance for human beings to benefit from the properties of light elaborated in this paper. A novel approach originating from these ideas is Human Centric Lighting followed by a much larger concept, People Centric Buildings.

3.1. Human Centric Lighting

Houser defines Human Centric Lighting as "Evidence-based lighting solutions optimized for vision, performance, concentration, alertness, mood, and general human health and well-being. HCL balances visual, emotional, and biological benefits of lighting for humans, recognizing the role of light on human vision, psychology, and physiology" [19]. Boyce comes up with a similar explanation of this relatively recent term, emphasizing the visual and non-visual effects of light in the definition he makes for his editorial piece Exploring Human Centric Lighting [20].

Human Centric Lighting has become a popular topic with the advancement of light emitting diode (LED) light sources, which make it possible to easily manipulate the wavelength of the light delivered through the monochromatic character of these novel light sources. Using this property of LEDs, which was not possible before with conventional light sources, it is now possible to change the color of light, or in other words the wavelength content of the light, throughout the day to the benefit of the user. This makes it possible for the lighting design to mimic daylight or to omit the undesired wavelengths at certain times of the day to increase the motivation, alertness and mood of users; put in another way, to manipulate cognition along with visual comfort. Thus both aspects discussed in this paper, the visual and non-visual attributes of light are utilized in human centric lighting.

3.2. People-Centric Buildings

The concept of People-Centric buildings takes the Human Centric Lighting understanding several steps further by adding other building components into the equation, temperature, air and noise for the health, well-being and productivity of building occupants. A non-profit platform funded by the European Climate Foundation, Buildings 2030 has recently published a white paper on the subject “Building 4 People: People-Centric buildings for European Citizens in order to motivate European Union member states to meet the Conference of Parties - COP21 Paris Agreement goals and European Union’s 2030 climate and energy targets [21]. The white paper emphasizes the importance of lighting in terms of people-centric buildings and gives examples of applicTations made in school, office and hospital buildings, increasing the productivity, learning progress and cognitive functioning of the occupants of these different buildings.

4. CONCLUSIONS

Seeing may very well be the most important sensory input human beings receive. With scientific advancements, it became apparent that the human eye was not made only for vision and that light brought non-visual effects on the human body as well. Current research shows that there is still a lot that we don’t know about the complex relationship of light and the human cognitive system, but experimental studies provide promising results for improving the cognitive performance of human beings, their well-being, physiological conditions as well as mental health, a concept that has not been discussed in this paper, through manipulating lighting conditions. The fact that the discovery of the ipRGC photoreceptor cells coincided with the recent technological developments in the field of lighting, in other words LEDs becoming general lighting sources brought up the possibility of new lighting approaches. Human Centric Lighting, which previously translated into using higher CCT light sources can now be applied in its actual means if the lighting design is deeply elaborated according to the scientific findings in the literature.

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BIOGRAPHY

Lale Erdem Atılgan obtained her BSc, MSc and PhD degrees from the Electrical Engineering Department of Istanbul Technical University in 2004, 2007 and 2014 respectively. During her PhD studies, she received the Jean Monnet European Union Scholarship and spent over a year at the Light Technology Institute of Karlsruhe Institute of Technology, Karlsruhe, Germany, doing research on lighting technologies, specifically Light Emitting Diodes (LEDs). She’s a member of the International Commission on Lighting as well as the Turkish National Committee on Illumination. Her research areas are lighting technologies, LEDs, LED driver systems and energy efficiency. She’s currently a member of the academic staff of the Electrical Engineering Department of Istanbul Technical University.

PSD AND WAVELET ANALYSIS OF SIGNALS FROM A HEALTHY AND EPILEPTIC PATIENT

G. Kulakli and T.C. Akinci

Abstract**—**This study presents one EEG signal from a healthy person brain wavelet and two EEG signals from epilepsy patient one of them is patient normal brain wavelet ,other is while epileptic seizure. Data are validated for reliability and validity and are obtained from data records at the University Hospital of Bonn, Germany. The data compare using power density spectrum and continuous wavelet transformer.

Keywords**—***EEG, wavelet, power spectrum density.*

1. INTRODUCTION

EPILEPSY is one of the top five diseases in the world .It can be seen at any age. Seizures can be a sign of neurological disorder, leading to serious injury and loss of self-esteem. The seizures occur in the nerve cells (neurons) in the brain as a result of abnormally high electrical activity. During the seizure, the brain cannot work properly and sends faulty commands to the body. Except for seizures, the brain usually works normally. There are many different types of epileptic seizures. But the basic thing to keep in mind is that there are two types of seizures: partial (ie, seizures that start limited to a region in the brain) and generalized (those that start as common in the brain). However, the term commonly used herein does not mean a worse and more severe type of seizure. This nomenclature is used to describe epileptic seizures due to different causes.

In ancient times, epileptic crises are often thought to be the attack of evil spirits or the devil. It was thought to be an illness, requiring extermination, exorcism or other religious or social approaches. The EEG method was used in various animals like rabbit, monkey, before humans [5].

1.1. Number of people with epilepsy in WHO regions

N=105, these numbers are only indicative based on the information provided by Atlas respondents which is figure 1. The numbers have not been corrected for nonresponding countries [1].

1.2. What is an EEG?

EEG stands for electroencephalogram. EEG is the main diagnostic method in the diagnosis of epilepsy. The EEG works on the basis of registering the wavering in the electrical movement of the nerve cell within the same group in the brain. The electrodes are glued to the scalp and recorded. This review is not painful or harmful to health. No contact with electricity. In addition to the classical EEG devices, which are developed with the support of technology and connected with computers, telemetric investigations and video-EEG monitoring studies help to better evaluate epilepsy patients.

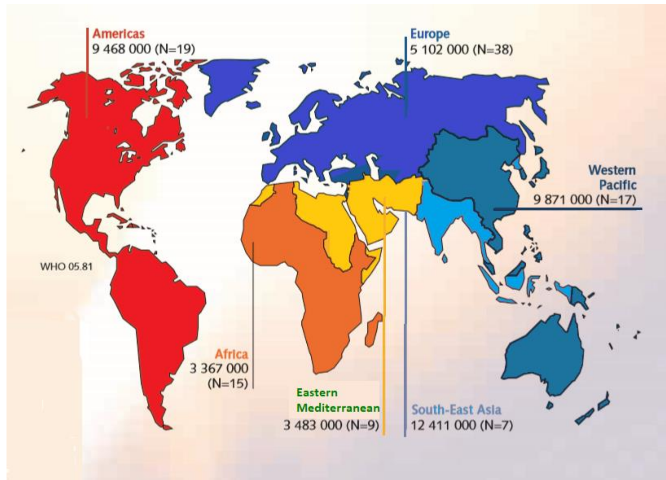

Fig.1. An auto: Number of people with epilepsy in WHO regions [1]

Since EEG examination is a short-term examination, the first examination may not detect any disorder. Short or long-term sleep examinations can be performed in clinically suspicious and recurrent conditions, with more than one EEG examination and even sleep deprivation.

1.3. Brainwaves

Brain waves change according to people's moment of thought or emotion. When slower brain waves are dominant, they correspond to tired, slow, sluggish, or dreamlike situations. However, higher frequencies predominate when over-awake or when our consciousness is open. Brainwave speed is measured in Hertz (Hz). There are six different types of brain waves from low to high frequency;

1.3.1. Infra-low

It is very difficult to detect them. Today there is not much information about the subject. Various research groups define this category.

1.3.2. Delta Waves (0-3 Hz)

This brainwaves are very slow, they has low frequency.
They are generated in deepest meditation and dreamless sleep. Everybody has delta wave in dreamless sleep.

1.3.3. Theta waves (3-8 Hz)

Theta brain waves are most commonly seen in sleep, but it is very easy to catch theta wave in deep meditation. Theta wave is our door to basic cognitive process, engram and discernment. In Theta, our senses are drawn from the outside and focus on the signals coming from inside.

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1.3.4. Alpha waves (8-12 Hz)

Alpha waves to indicate that the brain is restinting. Alpha waves help the general mental coordination, coolness, brain - body completion and learning.

1.3.5. Beta waves(12-38 Hz)

The most common pattern in the normal waking state. They occur when they are solving problems. When we pay attention to the outside world in daily life, Beta brain wave prevails. Beta brain wave is a fast activity that occurs when we are on alert, when our attention is concentrated, when there is, judgment, focused mental activity, problem solving or decision making

1.3.6. Gamma waves (38-42 Hz)

Gamma waves are the quickest of brain waves and relate to equitemporaneous processing of data from other brain areas. Gamma brain waves transmit information quietly and quickly to memory. Gamma brain wave is highly active in cases of superficial love, sacrifice and ın high virtues fire. It is estimated that gamma rhythms change perception and consciousness, and that the presence of more gamma rays is associated with the emergence of expanded consciousness and mental states.

2. EEG SIGNALS AND COMPARISON

The EEG signal from healthy person is plotted by red, EEG signal of healthy data of epilepsy patient plotted by blue, EEG signal at the time of epilepsy is plotted by black at figure 2 and figure 3 as the expansion and translation feature indicates, the master wavelet can form a base with the specified.

$$\boldsymbol{\psi}_{s,u}(\boldsymbol{t}) = \frac{1}{\sqrt{s}}\, \boldsymbol{\psi}\left(\frac{t-u}{s}\right) \qquad (2)$$

It is the translation parameter that specifies which region we are interested in s is the scaling parameter bigger than zero because of the fact that negative scaling is indescribable. The Multi-resolution feature provides set $\{\psi_{u,s}(t)\}$ is orthonormal. Conceptually, the fundamental coefficient of continuous wavelet transform $\psi_{u,s}(t)$. It is

$$Wf(s,u) = \langle f(t), \boldsymbol{\psi}_{s,u} \rangle$$
$$= \int_{-\infty}^{\infty} f(t), \boldsymbol{\psi} *_{s,u}(t)dt$$
$$= \int_{-\infty}^{\infty} f(t), \boldsymbol{\psi} *_{s,u}\left(\frac{t-u}{s}\right)dt \qquad (3)$$

Epilepsy is a common neurological disorder in which the normal activity of the brain is disrupted by excessive discharge of nerve cells.The seizure is the result of a sudden burst of electrical activity in the brain.

When the signals are overlapped, it can be clearly seen that the signals in epileptic seizures are more than the brain signals of the healthy individual or the normal brain signals of the epileptic patient.

Epilepsy seizures are divided into two groups as sequential, partial (focal) and generalized according to the distribution of abnormal electrical activity. Clinical symptoms vary according to the rate and localization of this activity.

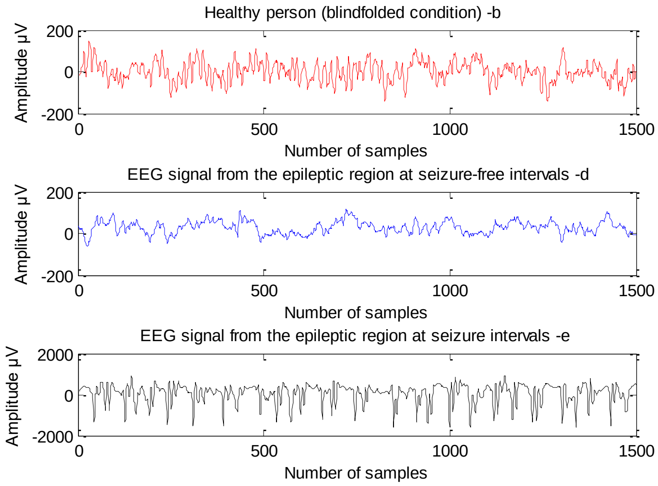

Fig.2. EEG signal of healty person (red),EEG signal of epilepsy patient non epileptic seizure(blue) ,EEG signal from epileptic seizure (black)

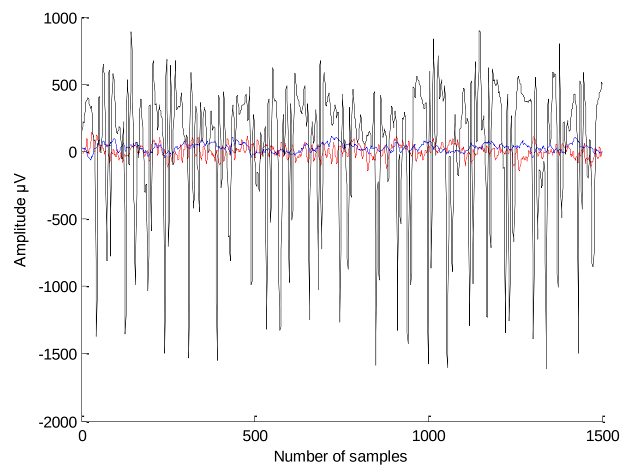

Fig.3. Overlapped signals of EEG signal of healty person (red), EEG signal of epilepsy patient non epileptic seizure(blue), EEG signal from epileptic seizure (black).

3. EEG SIGNALS AND COMPARISON USING POWER SPECTRUM DENSITY

For EEG analysis, there is no need to split the skull and insert the sensor into the brain. In the EEG analysis, electrical data is recorded by sensors placed on the head surface. 10 to 500 electrodes are used for EEG analysis. Because the electrical signals are too small, the recorded data is digitized and sent to an amplifier. Thus, the data is shown as the time-series of the voltage values [10].

A Power Spectral Density (PSD) is the measure of signal's power content to frequency. A PSD is typically used to characterize broadband random signals. The amplitude of the PSD is normalized by the spectral resolution employed to digitize the signal.

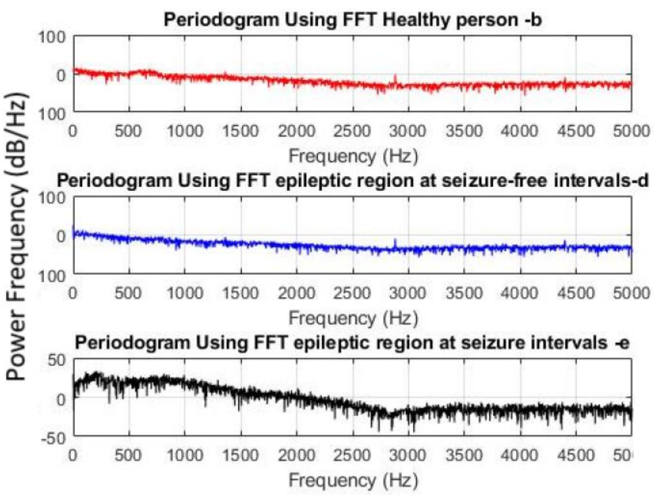

Fig.4. EEG signal's power spectrum density plot of healty person (red),EEG signal of epilepsy patient non epileptic seizure(blue) ,EEG signal from epileptic seizure (black).

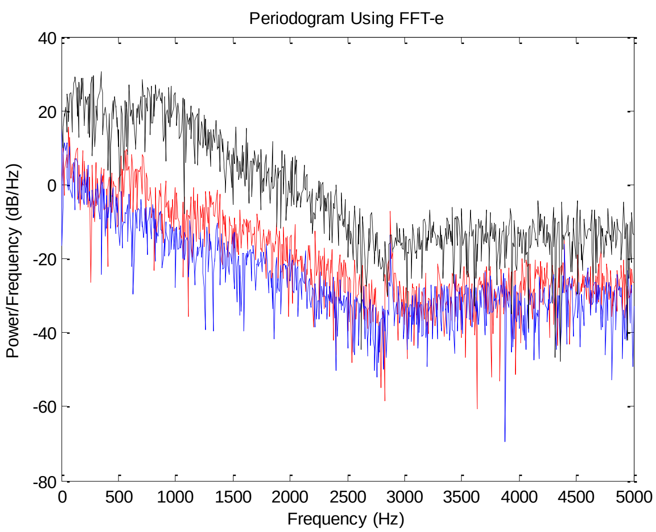

Fig.5. Overlapped EEG signal's power spectrum density plot of person (red),EEG signal of epilepsy patient non epileptic seizure(blue) ,EEG signal from epileptic seizure (black).

It can be observed very clearly at epileptic seizure moment brain signals have more energy than normal time and also it can be observed figure 4 and figure 5.

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Biographies

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OVERVIEW OF THE COGNITIVE SYSTEMS ENGINEERING

U. Korkmaz

Abstract**—**Cognitive Science, often called cognitive revolution, emerged as an intellectual movement in the 1950s. Cognitive science is an interdisciplinary scientific study of mind and thought processes, including philosophy, psychology, artificial intelligence, neuroscience, linguistics and anthropology. It examines the nature, functions and tasks of cognition. There have been some differences between the cognitive revolution in infancy and the current cognitive revolution. In today's cognitive revolution; artificial cognitive systems, as well as the results of the investigation of organisms and behavior are discussed. In studies on cognitive systems, it is important to draw attention to the potential benefits of the application and to emphasize its importance. The aim of this study is to examine the meaning of the cognitive system and the related disciplines and to examine the general researches on this subject.

Keywords**—***Cognitive, Cognitive Sciences, Cognitive Revolution, Reverse-Engineer.*

1. INTRODUCTION

STUDIES show that cognitive science was born in the mid-1950s [1-3]. After the birth of cognitive science, researchers in various fields have begun to develop theories of mind based on complex representations and calculation procedures. Griffiths showed how cognitive science has changed from the beginning in his study published in 2015. Cognitive science is based on the study of various fields of study including, the philosophy that formulates the right questions to guide any search for scientific knowledge, anthropology to understand the history and present of human culture, psychology and linguistics as a reflection of mental processes on behavior, and cognitive modeling which seeks to understand and translate the processes of neuroscience and mind processes that investigate the biological mechanisms of the brain [2, 4, 5, 8, 9]. Figure 1.1 shows the areas contributing to the emergence of cognitive science. Each line in the figure represents an interdisciplinary field of research involving disciplines to which it is connected [1,2].

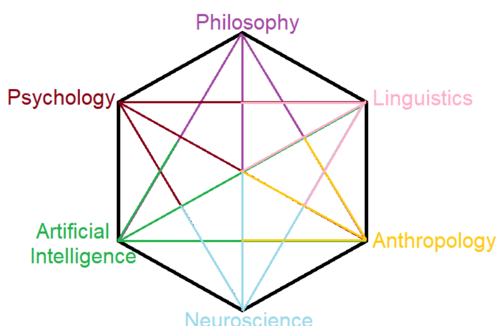

Fig.1.1. Illustrating the fields that contributed to the birth of cognitive science [1,2].

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Cognitive science is the study of thought, learning and mental processes that address the characteristics of psychology, linguistics, philosophy and computer modeling. It is examines the nature, functions and duties of cognition [6-13, and references therein]. Cognitive scientists examine the nervous system, intelligence and behavior by focusing on how the nervous systems represent, process, and transform knowledge [10,11]. Kell's study shows that researchers have been researching cognitive skills from past to present [14]. Cognitive science, some of the most complex and unclear processes that occur in our brain, is intended to apply these processes to machines as in reverse engineering [12, and references therein, 15]. In this sense, at the beginning of 1980, it was a version of movement or man-machine architecture to establish machine expert systems in artificial intelligence [16]. Figure 1.2 shows a schematic representation of the study in question [17].

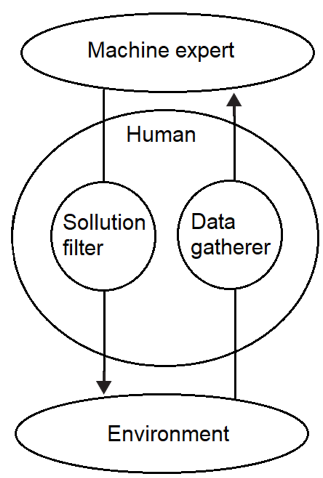

Fig.1.2. A version of an either/or human–machine architecture from the movement to build machine expert systems in AI in the early 1980s. [17].

Hollnagel and Woods (2005) examined the foundations of Cognitive System Engineering in detail. Cognitive Systems Engineering uses application, structure, purpose and restriction analysis to inform the design of process and technology when performing human-system integration [16-19]. When the analysis of cognitive science is made, it is seen that it covers many process levels ranging from learning, decision making, logic and planning to both the neural circuits and modular brain circuits [4,17]. It aims to produce new technologies that work like the human brain with the best understanding of the representation structures in mind and the calculation procedures working on these structures. For this purpose of cognitive systems, cognitive robots appear in the field of engineering [19-23].

From the 1950s to the present, cognitive science hypotheses have been subjected to various experiments while creating cognitive models. As mentioned above, the impact on many disciplines continues to grow. Because they study cognitive assets and interactions, social sciences are considerably enriched by a cognitive turn. Cognitive economy is included in

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this movement of social sciences. This turn can be defined as broad restrictions on the integration of individual and collective cognitive processes into economic theory and the specific constraints of dynamic interactions in economic processes [24]. The cognitive approach to economics proposes an interdisciplinary approach to human problem solving, selection, decision making and change studies to explain the nature and development of institutions and economic institutions in a context characterized by structural uncertainty [25].

2. COGNITIVE APPLICATIONS

Cognitive Systems Engineering applications appear in every aspect of our lives. These applications are increasing day by day in the field of health sector, restaurant, defense-security, economy-banking, consulting, company analysis and education. For example, digital assistants are designed to understand the problem and find solutions. It is a calculation in which the user and the application work together to determine what the problem is. Digital assistants have long been used in the healthcare industry and in customer engagement applications such as call centers. They also appear as personal investment consultants or investment advisor assistants in financial services. These practices address a specific problem, such as diagnosing a disease and recommending treatment for a particular individual. They can also help a call center representative solve a problem for a particular customer. Digital assistants offer sequential recommendations with supportive evidence at a given time, within the specific user's needs.

In contrast, recommendation practices follow news, activities or markets over time. It is the next step beyond a simple warning because they operate in a fluid environment where data, desires and company status can change. They understand business objectives, relationships between companies and people, past records of achievements or failures.

Searching for an unknown is another area of use for such cognitive applications. For instance, pharmaceutical companies use this application to combine data on patient outcomes, disease, clinical trials, and molecular structures in order to recommend previously unknown molecules as good candidates for new drug development.

Threats that emerged as the first common cognitive computer application were also identified. As they try to keep up with data attacks, banks, credit risk companies, government customs organizations or security agencies invest in cognitive information processing [26].

The studies of cognitive applications of firms such as O'Reilly AI, IBM's World of Watson, HP's Big Data Summit, Dataversity's SmartData and SAS Institute's Analytics Experience strongly emphasize the importance of cognitive systems.

3. CONCLUSION

In this study, the studies on the definition of cognitive science and interdisciplinary relations are examined. The study also examined the application areas of cognitive systems. The studies, and especially the investments made by the pioneering organizations in this field, show that it is a focus of interest with the increasing acceleration from the beginning of Cognitive Science. With the advancing technology and cognitive science, will it be possible to make machines that make their own decisions?

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BIOGRAPHIES

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A DATA DRIVEN STRUCTURAL HEALTH MONITORING APPROACH INTEGRATING COGNITIVE CONCEPTS

B. Gunes

Abstract— The most crucial step of the structural health monitoring (SHM) methodology is the detection stage where a decision on the existence of damage has to be made. Without a very detailed and refined finite element model of the system, data driven approaches have the potential for rapid assessment of the structure at the damage detection stage of the more encompassing SHM problem. Change in the dynamic properties of structures offers a real-time structural health monitoring technique which detects damage at low cost and with little or no human intervention. Whether the changes in the identified parameters are due to the onset of damage or due to factors introducing non-linearity to the system, such as closing and opening of micro-cracks in concrete structures, environmental conditions or noise present in the data is a challenge that needs to be faced. This study presents a pattern recognition type of approach that will help with the distinction of true and false positives. The first step of the model-free methodology includes the linearity check of the system. The recorded vibration measurements recorded from the structure is divided into time segments and with each data set modal parameters are identified. The variability of the identification results are used as a measure for the existence of confounding factors that may mask accumulation of damage revelation. An 'expert' knowledge gained through this allows better treatment of the uncertainties in the problem and mimic the human decision process. The results of the numerical simulations are promising for the effectiveness of the procedure to minimize 'false negative' identifications.

Keywords— *Data Driven Damage Detection, Structural Health Monitoring, Cognitive, Cognitive Concepts*

1. INTRODUCTION

THE need for a rapid assessment of the state of the critical and conventional civil structures have been demonstrated during recent earthquake disasters. The problem with the current practice is the shortage of experienced inspectors and inevitable time delays. These problems are compounded when the signs of damage are not visible and the structure being inspected is not readily accessible.

Structural health monitoring (SHM) methodologies are being explored extensively as a possible means to an automated damage characterization strategy for detecting, locating, quantifying damage and if possible predicting the remaining service life of a structure in a timely manner. SHM employs both local and global methods of damage identification to achieve this objective. The local methods include visual inspections and non-destructive evaluation tools whereas global methods work with measured vibration data and data mining methods [1-5] for achieving this objective.

The limitation of the local methods is that they are not practical for application to large and complex structures but more so to investigate specific components of a structure. Most of the global methods, on the other hand, exploit changes in modal parameters and to identify the extent and location of damage in large structures. The basic idea behind these techniques is that the vibration characteristics or the so-called modal parameters (frequencies, mode shapes and modal damping) are functions of the physical properties of the structure (mass, energy dissipation mechanisms and stiffness) and damage will in turn cause changes in the modal properties. The problem that is most commonly considered is the one where data are recorded at two different times and it is of interest to determine if the structure suffered damage in the time interval between the observations. *Damage*, within this context, is defined as any unfavorable changes in the physical properties of the structure. The behavior of the system during the data collection is typically assumed linear and the damage, which may result from an extreme event occurring inside the time segment, is characterized as changes in the parameters of a linear model. Hence linear methods are utilized to analyze the two signals, namely before and after the damage. In Civil Engineering applications, however, the assumption of linearity is hardly ever satisfied. Even in cases of relatively low excitation amplitudes, closing and opening of micro-cracks in concrete structures, yielding of regions with high residual stresses in steel structures, and the ever present interaction between the structural framework and non-structural elements, introduces nonlinearity in the response which will definitely affect the accuracy of the analysis. Furthermore, most of the damage detection techniques generally neglect the effect of environmental factors including changes in loads, boundary conditions, temperature, and humidity, on modal parameters. Whether the changes in the identified parameters are due to the onset of damage or due to such other factors is the most challenging aspect of the damage identification problem. This paper examines cognitive concepts to discriminate the changes of modal parameters due to inherent non-linearity of the system from those caused by structural damage. We attempt to establish a systematic approach to distinguish the differences in the identified natural frequencies due to damage versus natural variation due to the existence of mild non-linearities.

2. MODAL IDENTIFICATION WITH OBSERVER KALMAN FILTER

A theoretical framework that has proved convenient and fruitful for the development of mathematical models from input/output data is the state-space approach. Among methods that operate entirely in time domain, the Observer/Kalman Filter Identification (OKID) algorithm has shown to be efficient and robust. The most noteworthy feature of the algorithm is the introduction of an observer that transforms the mathematical structure to one where the eigenvalues of the

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system matrix are zero for noiseless data or nearly zero when noise is present. A consequence of the modification introduced by the observer is that the non-zero length of the modified system's pulse response functions is drastically reduced when compared to those of the original system, with important gains in efficiency and robustness resulting. In effect, the OKID algorithm treats the output data as resulting from a modified input on a modified system. The matrices of a minimum realization for the actual system are then subsequently obtained for the modified system. The name Observer/Kalman derives from the fact that the gain of the introduced observer is that of a Kalman filter [6].

The eigensystem realization algorithm (ERA) was first proposed by Juang and Pappa (1985) for modal parameter identification and model reduction of linear dynamical systems and was later refined and ERA with data correlations (ERA/DC) was formulated to handle the effects of noise and nonlinearities [8].Operating on pulse response functions, also known as Markov Parameters, this technique produces an input/output mapping having the smallest state vector dimension that is compatible with a given accuracy. This mapping is known as a realization and has the form

$$\dot{x} = Ax + Bu \tag{1a}$$

$$y = Cx + Du \tag{1b}$$

where x = state vector, y = output vector, and the matrices A,B,C and D are the result of the realization. Since the same input/output mapping of Eqs.(1) is also given by:

$$\dot{z} = T^{-1}AT\,z + T^{-1}Bu \tag{2a}$$

$$y = CT\,z + Du \tag{2b}$$

It is evident that the matrices that define the realization are not unique (except for D which is independent of the non-singular transformation matrix T). Note, however, that since the system matrices of any two realizations are related by a similarity transformation, the eigenvalues are preserved.

In order to carry out the system realization with the extracted impulse response data, the discrete counterpart of the continuous state-space model can be expressed as

$$x(k+1) = A_1 x(k) + B_1 u(k) \tag{3a}$$

$$y(k) = Cx(k) + Du(k) \tag{3b}$$

For a system with r input and m measurement vectors, the system response, $y_j(k)$ at time step k due to unit impulse u_j can be written as

$$Y(k) = \begin{bmatrix} y_1(k) & y_2(k) & \cdots & y_r(k) \end{bmatrix},\ k=1,2,\ldots \tag{4}$$

and form the $ms \times rs$ Hankel matrix

$$H(k-1) = \begin{bmatrix} Y(k) & Y(k+1) & \cdots & Y(k+s-1) \\ Y(k+1) & Y(k+2) & \cdots & Y(k+s) \\ \vdots & \vdots & \ddots & \vdots \\ Y(k+s-1) & Y(k+s) & \cdots & Y(k+2(s-1)) \end{bmatrix} \tag{5}$$

where s is an integer that determines the size of the matrix. By definition, the submatrices $\boldsymbol{Y}(k)$ correspond to the system Markov parameters and can be expressed as

$$Y(0) = D \tag{6a}$$

$$Y(k) = CA^{k-1}B \qquad k=1,2\ldots \tag{6b}$$

The basic formulation of ERA starts with the factorization of the Hankel matrix using the singular value decomposition,

$$H(0) = U\ S\ V^T \tag{7a}$$

$$H(1) = U\ S^{1/2} A\ S^{1/2} V^T \tag{7b}$$

Thus, the following triplet is a minimum realization:

$$\hat{A} = S^{-1/2} U_1^T H(1) V_1\ S^{-1/2} \tag{8a}$$

$$\hat{B} = S^{1/2} V_1^T E_r \tag{8b}$$

$$\hat{C} = E_m^T U_1 S^{1/2} \tag{8c}$$

where E_m^T is $[I_m\ O_m \cdots O_m]$ and E_r^T is $[I_r\ O_r \cdots O_r]$ and Oi is a null matrix of, Ii is an identity matrix of order i.

The basic formulation of the ERA requires the system's Markov parameters. An accurate identification of the Markov parameters is vital for accurate system realization. Identification of the system Markov Parameters has traditionally been carried out by Discrete Inverse Fourier Transformation (IDFT) of Frequency Response Functions (FRF). The approach used here, however, solves for the Markov Parameters directly in the time domain. The approach avoids the well-known difficulties associated with time-domain deconvolution by the introduction of an observer. The observer, when appropriately selected, leads to a state-space representation where the output is mapped to a modified input by a system whose pulse response functions decay much faster than those of the original system. As one anticipates, the Markov Parameters of the original system can be recovered from the observer gain and the Markov Parameters of the Observer Model.

The State-Space Observer Model is readily obtained from Eqs. (1). Specifically, adding and subtracting Gy to Eq. (1a) and defining

$$v = \begin{bmatrix} u \\ y \end{bmatrix} \tag{9}$$

one gets

$$\dot{x} = \overline{A}\,x + \overline{B}\,v \tag{10a}$$

$$y = Cx + Du \tag{10b}$$

where;

$$\overline{A} = A + GC \tag{11}$$

and

$$\overline{B} = [B + GD \quad -G] \tag{12}$$

Provided the system is observable, the eigenvalues of the modified system matrix Eq. (11) can be placed arbitrarily. One very attractive alternative is to select G such that all the eigenvalues of $\bar{A}$ are zero. In this case the resulting system matrix is nilpotent and the Markov Parameters of the Observer Model become identically zero after a finite (typically small) number of time steps. Because of the close relationship between the gain G that leads to zero eigenvalues in $\bar{A}$ (dead-beat observer) and the Kalman Filter, the foregoing approach is known as the Observer/Kalman Filter Identification (OKID) technique. In practice, the term is in fact generally used to refer to the complete process of identifying the pulse response functions followed by the generation of a minimum realization, typically using ERA/DC [8]. Once the system realization is obtained, the eigenvalues () and eigenvectors () of the state matrix A and the state-to-output influence matrix C can be used to obtain the modal parameters.

3. NUMERICAL SIMULATIONS

The numerical simulations are performed on the shear building model of a one-story one bay frame given in Figure 1. For the perfectly linear healthy state, the modal parameters of the structure are listed in the figure. The input excitation is taken as horizontal ground motion.

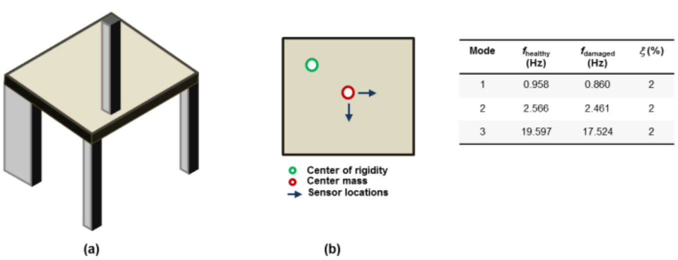

Fig.1. Simplified 3-D model for the numerical simulations: (a) Elevation view (b) Plan view

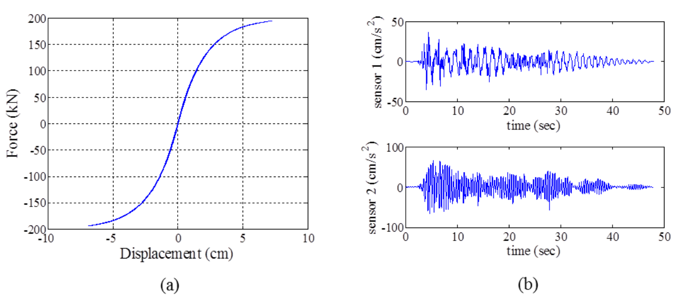

Fig.2. (a) Restoring force vs displacement relationship for the wall (b) Simulated acceleration measurements at the mass center of the floor

As part of the attempt to discriminate the changes in the modal parameters due to non-linearity of the system versus those caused by structural damage, the restoring force relationship for the shear wall is assumed to display Bouc-Wen [9] type non-linear behavior with parameters that result in smooth transition to non-linear softening behavior as shown in Figure 2. The acceleration response at the indicated sensor locations are analytically computed and sensor noise is simulated by contaminating both the input and the analytically computed acceleration response for all four floors with white noise having an RMS equal to 10%. The simulated acceleration measurements are also plotted in Figure 2. The 2500 point, 50 sec. long response data set is divided into 14 sec. long segments and consecutive segments are overlapped by a ratio of 5/7. ERA-OKID procedure is carried out for each segment and the modal parameters displayed in Table 1 are identified.

TABLE I
MODAL IDENTIFICATION RESULT

Data Set	Linear: No Damage		Linear: Damage		Non-Linear: No Damage	
	f_1(HZ)	ξ_1 (%)	f_1(HZ)	ξ_1 (%)	f_1(HZ)	ξ_1 (%)
1	0.96	2.09	0.83	2.13	0.69	13.88
2	0.96	2.10	0.83	2.02	0.70	12.67
3	0.96	2.19	0.83	2.14	0.74	14.04
4	0.96	2.21	0.83	2.11	0.77	16.50
5	0.96	2.38	0.83	2.22	0.80	12.47
6	0.96	2.31	0.83	2.59	0.81	9.31
7	0.96	2.73	0.83	2.68	0.81	7.75
8	0.96	3.14	0.83	3.24	0.82	6.79
9	0.96	3.00	0.84	3.46	0.86	5.80
10	0.96	3.10	0.84	2.25	0.90	3.91

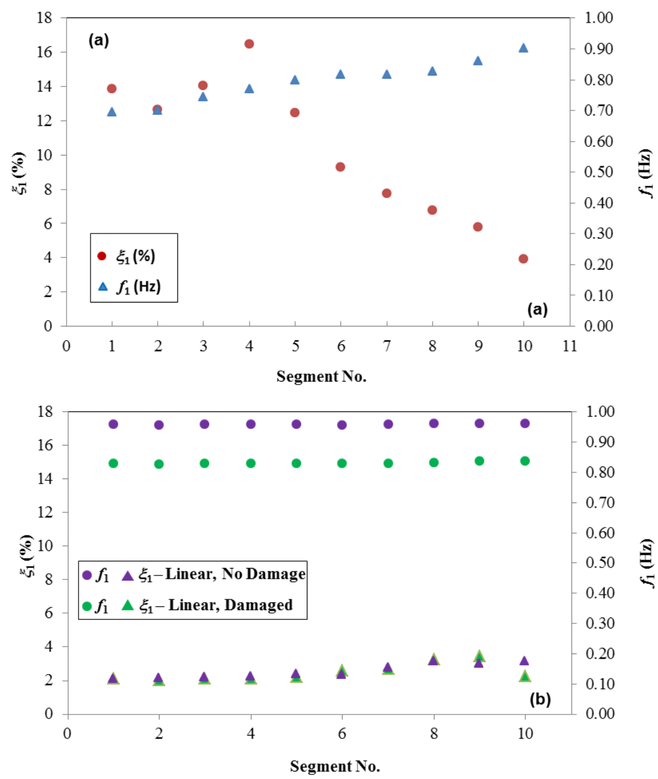

Fig.3. Identified Parameters for Mode 1: (a) Non-linear case (b) Linear case

Figure 3(a) and 3(b) display the variation of the estimated damping ratios and the natural frequencies for the first mode using different data segments with ERA-OKID algorithm for the linear damaged and non-linear cases, respectively. As clearly indicated in the figure, for the linear case, both for healthy and damaged states, the variability in the modal parameter estimates are small. The mean estimated values for the fundamental mode are f_1=0.96 Hz and ξ_1=2.52% with a standard deviation of 0.42% for the undamaged case and f_1=0.83 Hz and ξ_1=2.48% with a standard deviation of 0.50% for the damaged linear case. For the nonlinear case however, nonlinearity in the response manifests itself with increased damping ratio estimations having high variability (μ=4.17, σ=10.31). For the linear damaged case, however variability in the damping ratios is much smaller (μ=2.48, σ=0.50). It should also be mentioned that although the singular value decomposition of the Hankel matrix indicates the order of the system clearly during realization for the perfectly linear case, with nonlinear behavior it becomes harder to determine the order using the singular values and nonlinearity starts appearing as fictitious modes.

4. CONCLUSIONS

In this work, a damage detection methodology has been introduced. The proposed methodology is just an initial step in a damage characterization problem where a decision has to be made on the existence of damage. The initial examination with simulated data had promising results its capability for detection stage. Although the training data included loss of stiffness as the simulated damage and mild non-linear softening restraining force-displacement relationship, it can be easily expanded to different damage scenarios and force-displacement relationships including inelastic behavior. The variability in the extracted information proved to be very useful in discriminating between the simulated cases of ‘nonlinear behavior’ versus ‘damage’. Although this work did not focus on the further localization of damage but just the distinction between presence or absence of damage, this type of ‘insight’ may allow the ‘expert’ to better treat the uncertainties and provide reliable detection of damage. Further work will have to involve different structural configurations with different damage scenarios including multiple locations so that the ‘training data’ includes a more comprehensive data base content.

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