ABSTRACTS

of scientific papers of eng. Firgan Nihatov Feradov, PhD submitted for application– posted in ДВ №31/19.04.2022 - for associate professor in professional field 5.2. "Electrical engineering, electronics and automation" for the course in "Digital signal processing" at the department "Electronics and microelectronics", Faculty of "Information technologies and automation"

For the application a total of 19 peer-reviewed scientific papers are presented. A short summary of the papers is shown in Table 1.

Table 1. *Scientific papers*

Type	Number
Papers	19
Papers indexed in the SCOPUS data base	18
Papers indexed in the IEEE eXplore data base	12
Papers indexed in the Web of Science data base	2
Papers with full authorship	5

The presented scientific papers are separated into three groups – В4, Г7 и Г8 - in accordance with the categorization, defined in ***„Minimal national requirements for academic positions"***

[Indicator B4] Scientific work for associated professor - publications indexed in internationally recognized data-bases.

[B4.1] Van den Bossche, A., Bikorimana, J. M. V., & Feradov, F. (2014). Reduced losses in PV converters by modulation of the DC link voltage. Renewable Energy and Power Quality Journal, 1(12),

This paper aims to present how the PV converter losses can be reduced by employing a polypropylene capacitor in the DC link and to modulate that DC voltage. By using this approach a problem of controllability and stability arises. For addressing of these issues two current control methods - constant off time and a PWM type with second order high pass filter DC-link feedback - are presented.

The work presents a converter topology that uses a three-phase bridge, but it uses it in a different way for single-phase injection. The topology is used as a LCL filter, with a boost or buck conversion action in between. The advantage in this case is a lower current ripple at both input and output of the circuit, lower losses because of limited switching of some of the transistors, and limited voltage at the capacitors. In general losses in a PV converter originate from different sources. One non-negligible source is from the switching of the power electronic devices. Since the switching is at high rate of current, the DC link bus must have a low ESR capacitor in order to reduce the losses. If a polypropylene film capacitor is used, the ripple current is less limiting.

For the control of the circuit the "constant off time peak current control" (COPCC) is chosen since it has the advantage to include protection in the same item as the control. It switches off when the set current is reached and then a fixed off time is applied. The selected approach is examined both trough simulations and practical experiments. The simulation goal is to test the dynamic of the DC link of the PV converter topology using the naked COPCC and the COPCC with high pass filter feedback. Adding a high pass filter feedback into the constant off time current control, improves the stability of the system. The input voltage is 100 V and the output voltage is 200 V. The current reference as voltage image is 6 Amps with superimposed square wave of 1 Amp amplitude, and a frequency of 125 Hz.

The step up is mainly composed of a power stage, a constant off time current control and an over voltage protection. The practical experiment is based on the conducted simulation. In the step up mode, the system is stable without feedback, whereas in the step down mode, the system is even unstable in open loop. The analyses of the system are made by referring on the simulation and lab experiments results. In addition the presented COPCC the paper also examines a PWM high pass filter feedback control technique, which although slower in its reaction time is simpler to implement and does not require a microcontroller for its implementation.

Following the observations in presented work it can be concluded that for single phase grid injection, a three-phase bridge topology can be used while using the left leg as a boost converter and with reduced, film type DC-link capacitor. However, the behaviour tends to have a pronounced resonance for the step-up converter; for the H-bridge it is even unstable. One hand, this pronounced resonance can be damped using an analog constant off time peak current control using a first order high frequency filter to stabilize the resonant frequency. On the other hand it can be controlled by a fast duty control in a digital processor, while sampling a second order high pass filter. At low instantaneous grid voltage, the H-bridge is modulated. When the grid voltage is higher than the DC input voltage, the current to the grid can still be controlled with the step up converter without switching in the H-bridge. The controllability of the current reduces the switching losses of the PV inverter.

[B4.2] Van Den Bossche, A., Dimitrova, E., Valchev, V., & **Feradov, F.** (2017). A simplified controller and detailed dynamics of constant off-time peak current control. *Journal of Electrical Engineering*, 68(5), pp. 390-395

The article presents a simple, low cost and low power consumption variant for constant off-time peak current control (COTCC). The advantage of such current control solutions is that they are unconditionally stable and fast and can combine a current control together with a current protection. The aim of presented work is to carefully examine simple schemes and basic transfer functions used in COTCC solutions. The typical applications for this control scheme are Photovoltaic (PV) boost converters, battery charging, power factor controllers, BLDC and Switched reluctance motor control. The wide tolerance of changes in inductance is also safe if the inductor saturates and would get a much lower value. Even in the presence of severe disturbances, the frequency never goes to infinite. This is in contrast with hysteresis control which can destroy the converter due to disturbances on the current measurement.

The operation of COTCC is based on the following principle: The transistor is turned on, when the current is higher than the peak current set value I_{LIMIT}, the transistor is turned off during a fixed duration. If the If the current remains too high, the transistor is kept off.

The initial examination of the work of constant off-time peak current control is conducted using two approaches: mathematical modelling and practical experimental study. A total of three mathematical modelling techniques are examined for the analysis of COTCC – time domain approach, transfer function analysis approach and frequency domain transfer function approach. In addition to the mathematical modelling of the control a Pspice simulation of the control circuit is conducted. The results show close to 4.2 μs time is needed before the ideal transistor is turned off. This is mainly due to the internal delay of the used integrated circuit. In the measurements of the practical test circuit delays depending of the level shifters is introduced and due to the current transducers are also observed.

A series of practical measurements have been conducted using a test setup of a boost dc-dc converter. The tests are conducted with input voltage of 100 V DC. Some of the parameters of the test inverter are as follows: the used inductor has 600H inductance, the load is 60.9 Ω in parallel to 20 μF capacitance. The current of the inductor was used as an input for the current control.

In conclusion it can be highlighted that a constant off-time current control has an excellent dynamic behaviour in the time domain, which is close to a dead-beat control within one switching period. In the frequency domain the transfer function can be approximated in a transfer function with a delay of half of the switching period and some sin(ωTs)/(ωTs) – type of function for the amplitude. At the half of the switching frequency, and odd multiples of it, a double amplitude occurs, and large phase shifts are observed. This is indeed the Nyquist frequency where the signal frequency and the mirror frequency interfere and add together. There is a steady state error, which can be corrected in feed forward. The constant off time control is not so easy to be implemented in processor circuits, but can be easily made with two low cost comparators integrating timing and Schmitt-trigger action in a small scheme. The experiments and Pspice simulation correspond well and do not change the practical behaviour, except for some propagation delay time.

[B4.3] Dukov, N., Bliznakova, K., **Feradov, F**., Buliev, I., Bosmans, H., Mettivier, G., Russo, P., Cockmartin, L. and Bliznakov, Z., (2019). Models of breast lesions based on three-dimensional X-ray breast images. *Physica Medica*, 57, pp. 80-87.

This paper presents a method for creation of computational models of breast lesions with irregular shapes from patient Digital Breast Tomosynthesis (DBT) images or breast cadavers and whole-body Computed Tomography (CT) images. The approach includes six basic steps: (a) normalization of the intensity of the tomographic images; (b) image noise reduction; (c) binarization of the lesion area, (d) application of morphological operations to further decrease the level of artefacts; (e) application of a region growing technique to segment the lesion; and (f) creation of a final 3D lesion model. The algorithm is semi-automatic as the initial selection of the region of the lesion and the seeds for the region growing are done interactively. A software tool, performing all of the required steps, was developed in MATLAB.

For the purposes of the creation of an algorithm to segment tumour data from 3D patient images, 4 out of 50 sets from DBT of patients diagnosed with lesions were used. The number of tomosynthesis slices in these sets ranges from 40 to 60, each reconstructed tomosynthesis slice having a thickness of 1 mm. In the first case IMS unit, tomosynthesis sets are obtained from 13 projections, with a pixel size of 90 μm, acquired over an arc of 40 degrees, while for the second case the number of mammography projection images with a pixel size of 85 μm is 25, acquired in an arc of 50 degrees.

The method was tested using two types of assessment: 1) by comparing the segmented tumour masses after automatic tumour segmentation to the one outlined by expert radiologists; 2) by comparing a ground-truth tumour volume with the one obtained after applying the segmentation algorithm on a synthetic volume, obtained from virtual X-ray tomosynthesis study with a computational breast with this ground-truth tumour model introduced.

Using the first approach experienced radiologists evaluated the segmentation of the tumours in the slices and the obtained 3D lesion shapes. The segmentations performed by the radiologists and the corresponding results of the algorithm were compared with the help of the following metrics: Dice similarity coefficient (DSC), Percentage relative volume difference (RVD), VOSA (VOlume Selected by the Algorithm), VOSR (VOlume Selected by the Radiologist). The radiologist concluded for a quite satisfactory delineation of the lesions. In addition, for three DBT cases, a delineation of the tumours was performed independently by the radiologists. In all cases the abnormality volumes segmented by the proposed algorithm were smaller than those outlined by the experts. The calculated Dice similarity coefficients for algorithm-radiologist and radiologist-radiologist segmentations showed similar values.

For the second approach a selected tumour case was introduced into a computational breast model to recursively assess the algorithm. The relative volume difference between the ground-truth tumour volume and the one obtained by applying the algorithm on the synthetic volume from the virtual DBT study is 5% which demonstrates the satisfactory performance of the proposed segmentation algorithm. The developed software tool was used to create models of different breast abnormalities, which were then stored in a database for use by researchers working in this field.

In conclusion the proposed algorithm will facilitate the processing of any new sets of DBT and BCT images, as well as images from breast cadavers and whole body CT and can speed up the development and population of databases containing various tumour models.

[B4.4] Bliznakova, K., Dukov, N., **Feradov, F**., Gospodinova, G., Bliznakov, Z., Russo, P., Mettivier, G., Bosmans, H., Cockmartin, L., Sarno, A., Kostova-Lefterova, D. and Encheva, E., (2019). Development of breast lesions models database. *Physica Medica*, 64, pp. 293-303

The paper present the development and contents of the MaXIMA Breast Lesions Models Database, which is intended to provide researchers with both segmented and mathematical computer-based breast lesion models with realistic shape.

The database contains various 3D images of breast lesions of irregular shapes, collected from routine patient examinations or dedicated scientific experiments. It also contains images of simulated tumour models. In order to extract the 3D shapes of the breast cancers from patient images, an in-house segmentation algorithm is developed for the analysis of 50 tomosynthesis sets from patients diagnosed with malignant and benign lesions. In addition, computed tomography (CT) scans of three breast mastectomy cases were added, as well as five whole-body CT scans. The segmentation algorithm includes a series of image processing operations and region-growing techniques with minimal interaction from the user, with the purpose of finding and segmenting the areas of the lesion. In addition to the tumour models obtained by image segmentation mathematically modelled computational breast lesions are also stored in the database. The approach for generation of mathematical breast lesions models is based on the 3D random walk algorithm, generated in a predefined 3D volume, which in fact is an empty three-dimensional matrix.

The presented MaXIMA Imaging Database contains 50 breast cancer models obtained by segmentation of 3D patient breast tomosynthesis images, 8 models obtained by segmentation of whole body and breast cadavers CT images and 80 models based on a mathematical algorithm. Each record in the database is supported with relevant information. Two applications of the database are highlighted. The first one is inserting the lesions into computationally generated breast phantoms. The introduction of the breast lesions into the generated breast models is a crucial task, which defines the realism of the projected anatomic details onto the 2D image (and subsequently tomosynthesis image) model breast lesion. The second application is aimed towards generating mammography images with variously shaped breast lesion models from the database for evaluation purposes. In this approach projections of targets (the breast lesions) are simulated and then inserted at different positions in the clinical mammograms. This allows for: 1) the generation of x-ray projection images of 3D breast lesions by using an in-house developed software application, capable to simulate the x-ray transport through the computational lesions, and 2) the convolving of the generated images with an anonymized planar and free of breast lesions patient mammography image and using it in evaluation assessments (research) and in educational activities.

Both cases demonstrate the implementation of multiple scenarios and of an unlimited number of cases, which can be used for further software modelling and investigation of breast imaging techniques. In particular, they are very important when new technology is under design, development, testing and optimization.

The developed database serves an imaging data source for researchers, working on breast diagnostic imaging and on improving early breast cancer detection techniques, using existing or newly developed imaging modalities. The created database interface is web-based, user friendly and is aimed to be made freely accessible through internet and serve as an imaging data source for researchers, working on breast imaging and early breast cancer detection. In addition to boosting the research activities, the database is expected to represent also an attractive educational tool in the general field of Medical Physics and Biomedical Engineering.

[B4.5] Dukov, N. T., **Feradov, F**. N., Gospodinova, G. D., & Bliznakova, K. S. (2019). An approach for printing tissue-mimicking abnormalities dedicated to applications in breast imaging. Paper presented at the *2019 28th International Scientific Conference Electronics, ET 2019 - Proceedings*

Development of new breast tumour detection systems relies on the virtual clinical trials, which insist availability of a large number of images with realistic looking pathologies. For this purpose, as realistic as possible models of the breast with lesions are needed. The goal of this study is to create and evaluate a methodology for generation of realistic three dimensional (3D) models of breast tumours with irregular shapes and collect them into open source database.

The proposed procedure for printing of models of breast tumours can be performed either with computational tumour models, obtained from patient data, or from computational tumour models from a mathematical algorithm. The processing steps involve extracting the data from either the mathematical or the patient models to STL files. The STL file for a given tumour model is then loaded in a 3D printing software, where some additional post-processing can be performed. These can involve either smoothing the surface of the tumour model or resizing. Smoothing of the tumour model might be needed in the case where the 3D data was from patient data with poor resolution for example.

In the presented study the patient data for the computational tumour models is mainly from digital breast tomosynthesis and computed tomography of breast mastectomy. The computational algorithm for the creation of tumour formations with irregular shapes is carried out in two stages: 1) use of random walks for creation of the initial diffusive shapes, realized by either a Brownian motion or by Nearest Neighbor Random walks; 2) creation of a solid tumour shapes by applying a 3D filter and morphological operations. The 3D computational models based on patient data are created by segmenting the tumour masses from the patient images and stacking the data into a 3D matrix. The segmentation is performed with a semi-automatic in-house developed software segmentation tool.

Using the created 3D tumour models physical models of the lesions were printed using a LeapFrog Creatr 3D fused deposition printer. The printing of the tumour models was performed using black PLA (polylactic acid). Using the created tumour models physical breast phantoms were manufactured. The approach in manufacturing the physical breast phantoms includes modelling and printing the different components of the breast: skin, glandular tree and fatty tissue. In particular ABS was used to print the fatty tissues, while for the skin and the glandular tree the epoxy resins ware the best approach.

As a result of the conducted work a total of five different tumours were manufactured – four mathematically modelled tumours and one obtained from a segmented patient data. The created tumours are as follows: 1) Computer generated model using Brownian motion with size 14.9 x 14.9 x 14.9 mm printed using black PLA material; 2) Three computer generated models using Nearest neighbour with size 13.5 x 14.5 x 16.0 mm, 27 x 30 x 32.1 mm and 28.5 x 18 x 26.1 mm printed using black PLA material; 3) Segmented from real medical images with size 20.9 x 18.3 x 9.8 mm printed using black PLA material. The created tumours were placed in two physical breast phantoms. The material composition of the components used for the creation of the phantoms is as follows: 1) Container – PLA; Compartments – ABS; Duct tree – gray resin; Tumour – PLA; 2) Container – PLA; Compartments – gray and clear resin. The manufactured breast phantoms with the included tumour abnormalities were used for evaluation at clinical conditions such as absorption, contrast-enhanced and phase-contrast 2D and 3D x-ray.

[B4.6] Feradov, F., Marinov, S., & Bliznakova, K. (2020). Physical breast phantom dedicated for mammography studies. Paper presented at the *IFMBE Proceedings*, 76, pp. 344-352

The paper presents a methodology for creation of anthropomorphic physical breast phantoms dedicated for x-ray breast imaging. The use of physical phantoms in diagnostic radiology is a well-established approach for patient dose estimation, quality control of developed diagnostic systems and development of new breast imaging techniques. A combination of materials (Clear resin, Gray resin and PLA) and methods (fused deposition modelling and stereolithography) are used for the manufacturing of the breast phantom, which is subjected to an evaluation of its suitability for studies conducted using digital mammography. In particular, the created phantom is evaluated by using two sets of phantom images, taken using 22 kVp and 28 kVp, which are compared with real mammograms.

The main elements manufactured for the creation of the physical breast phantoms are the container, duct tree models and compartment models. The shape of the container is a semi-cylinder with sizes: radius of the semi-cylinder base 59 mm, and 49 mm height. Two 3D printing technologies are used for the creation of the phantom's elements: fused deposition modelling (FDM) and stereo-lithography (SLA). SLA technology and Clear and Gray resin are used for the creation of the glandular tree and the adipose compartments while the container is manufactured using FDM technology and PLA material. The semicylinder container was modelled with the help of DesignSpark Mechanical 2.0, while the glandular tree is modelled with BreastSimulator. The adipose compartments were based on segmented adipose models from tomography images of breasts.

For the experimental evaluation X-ray images of the physical phantom were acquired with a Siemens digital mammography unit featuring a detector with a pixel size of 0.085 mm × 0.085 mm. Two projection sets, each one comprising of ten images, were taken at tube voltages set to 22 kVp and 28 kVp, respectively. The source to detector distance was 660 mm. The evaluation is carried out with an in-house developed tool dedicated for feature extraction from x-ray images. In this study, a total of six features of interest are examined: Kurtosis, Skewness, Fractal analysis, Power law spectral analysis (PSA), GLCM (Gray-level co-occurrence matrix) energy and GLCM Contrast. The evaluation of the phantom is performed by comparison of features extracted from x-ray mammography images compared to features extracted from 20 mammography patient images. The described features are obtained over randomly selected ROIs in the analysed images and further averaged and expressed by a mean value and standard deviation.

For the calculations of the features, ROIs of size 128 × 128 pixels and 50% overlap of the regions are used. All ROIs are placed "inside" the projected breast, excluding skin, muscle and background. The conducted comparison of features shows a good coincidence between features from phantom and patient images. Better agreement is observed for the phantom images obtained with 28kVp, which is expected since this energy is traditionally used with mammography units.

The conducted comparative evaluation of the created physical phantom and the patient mammograms shows similarity between features extracted from their mammography images.

[B4.7] Marinov, A., Bekov, E., **Feradov, F.**, & Papanchev, T. (2020). Genetic algorithm for optimized design of flyback transformers. Paper presented at the *2020 21st International Symposium on Electrical Apparatus and Technologies, SIELA 2020 - Proceedings*

The paper presents an approach for designing transformers for flyback converters, based on the concept of computer aided design, where at its core is the utilization of a genetic algorithm. The genetic algorithm allows for optimal selection of critical transformer components and parameters, where the objective function - based on user preference - may include efficiency, cost, geometric size, thermal dissipation, weight and other parameters critical to the design.

The design approach includes ten steps. The overall flow can be described as: 1) User data input; 2) Trimming out incompatible transformer cores; 3) Generating a population using the remaining members of the database; 4) Testing the design population against the design constrains that are derived from the input data with incompatible designs being rejected; 5) remaining designs are tested against the fitness function (which can contain various user defined parameters that are weighted based on their design importance); 6) Most successful designs in regards to the fitness function are allowed to developed child strings trough crossover and mutation, where the process is iterated again until a design with satisfactory results is obtained.

The database used in the suggested approach is developed in XML format and includes three separate data structures. The first data structure describes core selection, the second core magnetic materials and third wires available for the designs. The first two data structures are involved directly in the Genetic algorithm, while the third is used as part of the design procedure itself – wires are selected based on the core and topology parameters offered by the algorithm. A procedure to remove members of the database, based on input design parameters is included.

The approach, with all its steps and specifics is developed into a Python script. The three database structures are populated, with a total of 374 cores, 5 materials and 56 wire types. The algorithm is tested over several different designs using various design procedures. It was noted that the algorithm is capable of producing successful designs with parameters that could be considered near optimum, while using a relatively low number of populations and epochs. The two major drawback that are observed include premature conversions and faulty designs generated despite various preventive measures.

The developed algorithm is evaluated using a task requiring the design of a flyback transformer with a single secondary winding is considered. The example is a low power (output power of 36W) grid fed design (VAC=240V/50Hz) operating in discontinuous mode. The envisaged reflected voltage for the design is VOR=70V. A reinforced isolation is required. The optimisation parameters include efficiency and weight. This exact design is selected for verification as it allows for lower leakage inductance and compact reinforced isolation (compared to using margins), while providing easy to automate design procedure as the wires are selected as a result of the provided core geometry. This type of design is widely utilized for flyback transformers.

After the execution of the algorithm a design which reduces the losses significantly was obtained, while the required weight was maintained at a constant value. Convergence is reached after the 7th epoch. Form the obtained results it can be concluded that the developed algorithm can generate correct and successful designs, offering low computation times and good design accuracy.

[B4.8] Marinov, A., **Feradov, F.**, Papanchev, T., & Bekov, E. (2020). Random forest algorithm in determining the viability of the implementation of synchronous rectification/operation in power electronic converters. Paper presented at the *2020 International Conference Automatics and Informatics, ICAI 2020 - Proceedings*

The paper presents the implementation of a random forest algorithm applied to decision making, when designing power electronic converters. The algorithm is used to aid topology selection and, more specifically, provide guidance in choosing synchronous operation/rectification or conventional diode application. The presented algorithm can be applied to both isolated and non-isolated converters – an example with an isolated converter is provided.

In the suggested expert system, decision-making support on whether synchronous rectification should be selected or dismissed for a certain design is based on the application of the Random Forest algorithm. The random forest algorithm was chosen for this specific task due to its several distinct advantages, among which: good predictive performance, reliable feature importance estimation, ability to perform prediction with missing data, etc.

The first elements required for the training and implementation of the system are a training input and target values. The target values have two classes, as the topologies can either utilize a MOSFET or a diode – synchronous or conventional topology. The training input includes the following parameters that should be universally applicable over different topologies and that the user has to provide for estimation: Input voltage, Output voltage, Output current, Operational frequency, Current ripple, Cost weight and Efficiency weight. A significant problem for the implementation of the suggested random forest expert system is the availability of training and test datasets. During the study, preexisting data that can be used as a set was not found, thus training and test data sets were compiled specifically for the expert system. At its basis is the use of a brute force approach that calculates efficiencies of randomly generated designs over extensive databases of real diodes and transistors. Designs are rated based on a fitness function compiled in relation to cost and efficiency weights. Target value is determined based on the majority of diode or MOSFET designs present in the top *n* of the sorted designs.

The random forest algorithm for the suggested expert system is developed in the Python scripting language, where the Scikit-Learn library is used to generate the forest. This Python module provides all options and possible algorithm settings required for the compilation of the expert system. In order to verify the suggested expert system and evaluate its accuracy all of the steps and processes required for the creation of the system are consolidated in a script and tested for a specific topology. The test case chosen for the verification part involves the topology of a buck converter. This converter is chosen due to its relative simplicity and the easy evaluation of its efficiency. Based on the performed test an accuracy of 0.942 for the created system was obtained. In addition feature importance tests are performed in order to access the design process and priorities of the system.

In conclusion the paper presents an expert system for decision making when selecting synchronous rectification/operation over conventional diode rectification. The expert system is developed and training data is generated. The system is evaluated over a specific buck topology. Accuracy and feature importance are estimated. Based on results it can be concluded that the proposed expert system is effective and provides sufficient accuracy. As the expert system is developed in the open source Python scripting language it can be easily integrated in existing CAD software. Some limitations of the expert system can be noted: lack of accountancy for parallel operation and need to develop training sets for each topology.

[B4.9] Feradov, F., Mporas, I., & Ganchev, T. (2020). Evaluation of features in detection of dislike responses to audio–visual stimuli from EEG signals. *Computers*, 9(2)

There is a strong correlation between the like/dislike responses to audio–visual stimuli and the emotional arousal and valence reactions of a person. The present work examines the automated detection of dislike responses based on EEG activity when music videos are used as audio–visual stimuli. Specifically, we investigate the discriminative capacity of the Logarithmic Energy (LogE), Linear Frequency Cepstral Coefficients (LFCC), Power Spectral Density (PSD) and Discrete Wavelet Transform (DWT)-based EEG features, computed with and without segmentation of the EEG signal, on the dislike detection task.

The conducted study examines two different EEG preprocessing approaches and, in this context, the discriminative capacity of various EEG features is examined. The calculated features can be separated into two groups. In the first group of features are based on frequency decomposition with DFT, such as the PSD, Logarithmic Energy (LogE) and Linear Frequency Cepstral Coefficients (LFCC). The second subset of features is obtained using DWT-based decomposition with four different wavelet functions, such as Daubechies of order 4 and 32, Coiflets of order 5 and Symmlets of order 8. The two approaches used for the extraction of the features are trough 1) use of the whole EEG recording and 2) the separation of the EEG recording into separate frames and averaging the frames into a single frame.

The experimental evaluation was performed using EEG recordings from the DEAP dataset which consists of 32 subjects, each presented with 40 audio–visual stimuli. For the current experimental evaluation the data is split based on the *liking* ratings provided for each recording and two categories are formed —*negative (dislikes)* and *other*. Subjects, for which less than 20% of the total amount of data was tagged as negative, were excluded, and as a result data of only 24 participants in the database is used. A subject-dependent classification setup with a 10-fold cross validation was considered. Each of the examined feature types was computed for 60 sec. recordings with or without segmentation. For LFCC and LogE, we experimented with filterbanks consisting of 10, 15, 20, 30, 45 or 60 filters. For the DWT-based features, we experimented with four wavelet functions. Thus, a total of 18 sets of EEG feature types were calculated in each of the two preprocessing setups. The experimental evaluation was carried out using the WEKA machine learning toolbox implementations of four classification algorithms - Naïve Bayes (NB), Classification and regression trees (REP), kNN and rbf SVM.

Based on the presented common experimental protocol the eighteen EEG feature sets are evaluated. The average classification accuracy varies in a wide range depending on the specific combination of EEG features and classification method—between 53.8% and 98.6%. The lowest accuracy, 53.8%, is observed for the NB classifier with PSD_{All} features calculated for the entire signal. The highest average classification accuracy, 98.6%, was observed for the kNN classifier with WPT-db4 features computed for the entire signal. Identical average detection accuracy of 98.5% was observed for the other three wavelet functions: db32, coif5, and sym8.

In conclusion it can be highlighted that the two signal preprocessing approaches considered here serve as different representations of the EEG activity. Specifically, the averaged frames provide a compressed representation of the EEG signal, which contains information about the overall state observed during the recording of the signal. The features based on the entire signal convey information about the activity during the period, which the DFT-based features cannot capture.

[B4.10] Feradov, F., Ganchev, T., & Markova, V. (2020). Automated detection of cognitive load from peripheral physiological signals based on hjorth's parameters. Paper presented at the *Proceedings of the International Conference on Biomedical Innovations and Applications*, BIA 2020, pp. 85-88

The prolonged exposure to high levels of cognitive effort causes fatigue and stress-related decrease of attention and concentration, which are known to compromise work efficiency, safety and health. In the present study, we investigate the applicability of the Hjorth parameters, namely Activity, Mobility and Complexity, computed from peripheral physiological signals, as features on the automated cognitive load detection task. Specifically, here we consider detection of high cognitive load in a person-independent scenario based on galvanic skin response (GSR) and photoplethysmographic (PPG) signals.

The cognitive load detection task is a typical machine-learning task, which incorporates GSR and PPG signal preprocessing, feature extraction and post-processing, and classification stages. In the signal preprocessing stage the PPG and GSR signals are filtered, which aims to reduce artifacts, interferences from the power network, and other noises due to imperfections of the signal acquisition and transmission process. Next, the signals are segmented to short blocks of several seconds and each block is then subject of parameterization in order to extract a representative set of features. In the presented study the Hjorth parameters (Activity, Mobility and Complexity) are used as signal features, as they carry information about the variability of the amplitude, the variability of the temporal dynamics and the variability of the spectral bandwidth of the signal. Once calculated the features are scaled to the dynamic range of values [0, 1], in order to facilitate the classification stage.

The experimental setup is based on a subset of the CLAS dataset which contains PPG, GSR and ECG data from 60 participants, who are engaging in five different tasks: three problem-solving tasks - namely Math-test, IQ-test, Stroop-test – and two tasks aimed at eliciting emotional reactions. In the current study we aim at cognitive load detection and therefore we use only the recordings collected during the Math-task and the IQ-task. Traditionally the detection of high cognitive load is defined as a two-class decision problem, consisting in the discrimination between the "*cognitive activity*" and "*idle state*". Based on this approach the *Activity*, *Mobility* and *Complexity* features are computed based on the data for the Math-task and IQ-task using the PPG and GSR signals and feature vectors are formed. These feature vectors were computed from the data of 59 participants in the dataset with total of 7 combinations of features used for the vector formation. As a result 7 feature datasets are formed for each participant. Classification was performed using the Weka machine learning toolbox, with 4classification algorithms being employed – MLP, Logistic Regression (LR), rbf SVM and poly SVM.

The obtained experimental results show that the classification accuracy for the evaluated features and the different setups ranges from 43.2% to 84.7%. The lowest score of 43.2% is observed in setup using Activity and Mobility features, computed from PPG signals in the Math-task (cf. MLP classifiers). The highest classification accuracy of 84.7% was observed on the Math-task, when Mobility and Complexity features computed from GSR data are combined (cf. SVM classifiers with a polynomial kernel). The experimental evaluation demonstrated that the GSR signals provide relatively higher classification accuracy for the detection of cognitive load with Hjorth parameters. This observation holds true for both features computed based on Math-task data and IQ-task data.

Based on the experimental results, it can be concluded that Hjorth's parameters, computed for segments of PPG and GSR signals are applicable for the automated detection of states with increased cognitive load.

[B4.11] Feradov, F., Ganchev, T., Markova, V., N. Kalcheva "EMD-based Features for Cognitive Load and Stress Assessment from PPG Signals", Paper presented at *International Conference on Biomedical Innovations and Applications - BIA-2021*, Varna, Bulgaria, 2022, paper. #43

Work-related stress and fatigue due to high-cognitive efforts have significant social impacts and are among the leading causes of health problems in modern work environments. In the presented paper a study on the applicability of Empirical Mode Decomposition (EMD)-based features for detecting the stress level and cognitive load from PPG signals. These features are extracted by decomposing the PPG signal with the EMD and the subsequent estimation of certain statistical parameters from the resulting intrinsic mode functions.

The proposed method for PPG feature extraction builds on the EMD signal decomposition, followed by the estimation of a number of statistical parameters from the resulting intrinsic mode functions. Initially, the PPG signal is preprocessed to suppress artefacts and interferences and eliminate the non-relevant spectral components. After the filtration process, the signals are decomposed using EMD into intrinsic mode functions (IMFs) and a residual through. The resulting IMFs contain the natural AM-FM modes of the signal, which represent the oscillations that can be observed in the recorded signal. Once all IMFs for a specific PPG signal are obtained, they are split into non-overlapping fixed-length segments. Next, the following statistical parameters are estimated for all IMFs in each segments: maximal value, minimal value, median value, mean value and standard deviation. Finally, these statistical features estimated for all IMFs in a particular segment are grouped together in a single feature vector, which is next fed to the classification stage.

The assessment of the practical performance of the proposed statistical features is conducted using a common experimental protocol, which was purposely designed for detecting stress and fatigue during cognitive activity. Specifically, the experimental setup used PPG recordings from the publically-available CLAS dataset. In brief, the CLAS dataset contains recordings of physiological activity – PPG, GSR and ECG – of 60 participants, made while the participant are performing cognitive tasks or are watching emotion-eliciting videos and images. In the current experiments, only PPG signals recorded while the test subjects solve cognitive tasks are used. During the first step of forming the person-specific classification datasets, the filtering and EMD procedures are performed on the entire PPG recording, which includes the signal collected over the three cognitive tasks -- math, IQ and Stroop test. Once the statistical feature estimation process is complete, a class assignment procedure is carried out based on the duration of the math, IQ and Stroop tasks. This way the feature vectors computed in such a manner are split into three equal parts, which correspond to the math, IQ and Stroop tests – *initial, middle* and *end*. In the experimental evaluation three classifiers from the Matlab Classification Learner environment are used – Decision tree, SVM and kNN.

A common experimental protocol is followed in all experiments. The obtained mean accuracy ranges from 88.8% to 72.4%. The highest accuracy was obtained with the Decision tree classifier in combination with features extracted from the recordings of PPG activity while the participants are carrying out the math test. The lowest mean classification accuracy was observed when the features from IQ test recordings are classified using a kNN classifier. The standard deviation in the results varies between 8.3% and 11.1%.

In conclusion it can be highlighted that the conducted study shows that the proposed PPG signal parameterization approach is applicable for tasks related to the classification of stress and fatigue. Future studies will aim to develop and evaluate more specific and useful features related to the Empirical decomposition of PPG signals.

[Indicators Γ7] Scientific publications indexed in internationally recognized databases.

[Г7.1] Feradov, F. N., & Ganchev, T. D. (2019). Spectral features of EEG signals for the automated recognition of negative emotional states. Paper presented at the *2019 28th International Scientific Conference Electronics, ET 2019 - Proceedings*

In the presented paper the properties of spectral EEG features for the detection of negative emotional states are investigated. In particular, the proposed features represent the dynamics of energy distribution in the frequency range of 20-35 Hz, based on a time-frequency analysis of multichannel EEG signal.

The calculation of the proposed spectral features is performed in three main steps. The first step consists of preprocessing, where initially the EEG signal is filtered for the suppression of artefacts and interferences, and then is segmented into frames using a sliding window with a fixed predefined length. During the second step, a Discrete Fourier Transform (DFT) is performed on each frame in order to obtain the spectrum. The third step is the actual calculation of descriptors. The proposed descriptors are defined as the difference between the value of the power spectrum computed for a given frequency of the first frame and the value of the power spectrum for the same frequency in subsequent frames

The EEG data for the experiments is taken from the DEAP database which consists of physiological recordings and facial videos taken while the participants are watching musical videos. Here the EEG data of only 10 participants from the database is used. The data of each participant is split in two groups – "*negative*" and "*other*". The separation was performed based on the provided "liking" rating which ranges from 1 to 9, where 1 is the lowest score (not liked) and 9 is the highest score (liked). The "liking" rating was chosen as a data separation criterion, as it implies a higher level of cognitive engagement when compared to the other available tags. Recordings of songs which had ratings lower than 4 were tagged as „*negative*", while recordings with rating over 4 were tagged as „*other*". The features are calculated using an overlap of 0.5s between subsequent frames is during the segmentation of the signals. Given that the length of each trial is 63 seconds a total of 125 frames are obtained. The features are calculated only for the frequency range 20 - 35 Hz. A total of 16 features are extracted from each frame and the process is identical for each EEG channel. This frequency band was chosen, as it is known to provide high amount of information about cognitive activity. The obtained feature data is loaded into WEKA machine learning toolbox and two classification algorithms are used – rbf SVM and C4.5 Decision tree. During the experiments a 10-fold cross validation was applied for both classification methods.

In total, twenty experimental evaluations with the proposed features were performed – one for each participant and each classification algorithm. Both classification methods demonstrated very high classification accuracy – 94.3% mean accuracy for C4.5 and 96.8% for SVM. The SVM algorithm showed higher results, with 5 cases where the classification accuracy exceeded 99.0%. The spread of the data, when using this approach, was 12.7% with lowest accuracy of 87.0% for Participant 22 and highest accuracy of 99.7% for Participant 32. In the case of J48 the range of obtained results was 4.8% with lowest accuracy of 92.9% for Participant 28 and highest accuracy of 97.7% for Participant 29.

Experimental results show that the proposed features allow achieving a high accuracy and can be used in tasks associated with automated detection of emotional states. In conclusion an argument can be made that the formation of emotions in response to complex tasks such as listening to music or watching movies and videos is highly interlinked with cognitive activity.

[Γ7.2] Feradov, F., & Ganchev, T. (2020). Identification of affective mental activity based on multichannel EEG signals. Paper presented at the *Proceedings of the International Conference on Biomedical Innovations and Applications*, BIA 2020, pp. 101-104.

The paper examines a method for automated identification of affective mental activity based on EEG signals. The proposed approach is computationally lightweight as it operates directly on the samples of the time-domain signal, without the need for complex preprocessing, frequency-domain transformation or another feature extraction steps. In a more general context, the paper examines the averaging of multiple EEG channels and the subsequent segmentation of the signal to short frames helps for obtaining indications about the overall mental activity at a specific time.

The examined feature extraction approach is carried out by sample-by-sample averaging of the channels of a multichannel EEG recording. The obtained averaged EEG signal is separated into frames and zero mean and unit standard deviation normalization is applied. The resulting values for the samples of the frames are used for model creation. In the conducted study three different approaches are examined for additional processing of the generated frames. The first approach directly uses the samples of the frames as features and no additional processing is applied. The second method uses the differences of neighboring frames in order to emphasize the temporal dynamics of the EEG activity. The third and proposed approach is the use of the differences between a fixed frame, reflecting neutral emotional state, and the generated frames of the EEG signal. In this way the obtained samples, which are used as features, reflect the difference between a given state of emotional affect and a neutral state.

For the experimental evaluation of the proposed methodology the DEAP dataset is used. DEAP is freely distributed and contains EEG recordings of multimedia induced emotional states. For the purposes of the selected experimental setup the data of each person, included in the dataset, was further split in four categories, based on the *arousal* and *valence* ratings provided by the participants. After the class assignment procedure is complete the features are calculated using the presented approaches. In the experimental evaluation only the first one-second segment is used to represent the emotionally neutral mental activity. The other 60 seconds of each recording were used to represent the EEG activity during the stimuli. The model creation and classification is carried out using the WEKA machine learning toolbox, using 3 classification algorithms – kNN, rbf SVM and C4.5 Decision tree.

The highest average classification accuracy obtained as a results of the conducted experimental was achieved using the proposed method for computing based on the calculation of fixed-frame differences. Specifically, using the kNN and SVM classifiers, an average classification accuracy equal to 98.4% ± 1.9% and 97.7% ± 2.1% was obtained, which is significantly higher than any other result. The other two signal processing methods for computing the feature vectors did not provide satisfactory classification accuracy.

In conclusion it can be pointed out that the proposed method significantly outperformed two related methods, which are based on the direct use of the averaged EEG signal values as input vectors and on the use of the differences between subsequent segments of the EEG signal. The most significant advantage of the proposed method is that it does not use frequency domain transformations in order to extract features and instead operates directly on the samples of the EEG signal, which in turn contributes to its computational efficiency.

[Г7.3] Feradov, F. (2020). Study on the relation between affective and cognitive states for automated EEG analysis. Paper presented at the *Proceedings of the International Conference on Biomedical Innovations and Applications*, BIA 2020, pp. 105-108.

The paper examines the relation between states of affect, used in the dimensional model of emotions, and cognitive brain activity. The analysis is performed using data provided in the DEAP database. In particular, an examination of the relation between the self-annotated ratings for EEG recordings - arousal, valence, dominance, liking and familiarity - made while the participants are watching music videos is performed.

DEAP contains EEG, peripheral physiological signals and facial video recordings of people watching different musical videos. There is a total of 32 participants, with 40 trials for each participant. Each trial is scored by the participant in accordance to the emotional reaction which the music video has elicited. The trials are rated using 5 criteria – Arousal, Valence, Dominance, Liking and Familiarity. The first three ratings - Arousal, Valence, and Dominance – are standard in tasks regarding analysis of emotional states. In addition to them two more ratings used to describe the emotional impact of the stimuli – Liking and Familiarity. The first three rating reflect more physiological reactions while Liking and Familiarity are connected to subjective, personal experiences. Liking indicates the level to which the participant has enjoyed each song. The final score – Familiarity – indicates to what degree the participant is familiar with the observed musical video. The inclusion of these two additional scores allows for an analysis of the relation between the subjective cognitive activity and physiological reactions to be made. Thus the conduced examinations are focused in two main directions.

The first one is the study of the change in score, related to Familiarity. This evaluation examines the change of mean score and standard deviation for different levels of Familiarity. The study aims to determine the degree to which prior exposure to different songs affects the listener's perception and scoring.

The second study is aimed towards liking score analysis. The Liking score indicates both a degree of emotional response to a given media (in this case musical videos) and a pronounced cognitive activity in the process of evaluation of the stimulus. The distribution of scores for different parameters (most prominently Valence) is an indicator of the relation between cognitive and physiological reaction.

The statistical evaluations are performed on scores from all participants in order to examine the relations as a non-person specific phenomena. It was observed that parameters, such as Familiarity and Liking, which can be considered strongly cognitive, have effect on the formation and perception of emotions. The conducted study showed that a priori knowledge of media based stimuli can lead to increased self-reported Valence and Liking scores. Additionally the examination of the relation of the latter two parameters suggested that cognitive activity and perception of the stimuli may differ from the induced emotion and can lead to differences between the recorded data of the experienced emotion and the accompanying annotation.

The obtained results suggest that experimental protocols for studies of emotional and affective states through analysis of EEG recordings should take into account the existing relations of the participants to the chosen stimuli.

[Г7.4] Feradov, F. (2021). Spectral features for the classification of familiarity from EEG recordings. Paper presented at the *2021 44th International Convention on Information, Communication and Electronic Technology, MIPRO 2021 - Proceedings*, pp. 323-327.

Familiarity with different objects or stimuli plays an essential role in forming behavioral and emotional responses. The present paper examines the applicability of spectral features in the classification of levels of familiarity from EEG signals. In particular it examining the differences of PSD of frequency bands and covariance coefficients as EEG features is carried out.

The first step of the feature extraction process is related to the preprocessing of the used multichannel EEG signals. The filtered signals are separated into segments using a sliding window with a fixed length of 1 second, with an overlap between subsequent frames of 50% (0.5 sec.). In addition to the extracted features two different signal conditioning approaches are used for the calculation of the PSD features: 1) extraction of features from all channels 2) averaging of data from different channels and extraction of features from a single averaged EEG signal.

The approach in which all of the channels are used for feature extraction is a standard and widely used EEG signal processing technique. The extracted features provide the most detailed information on the studied phenomena but result in data with high dimensionality and large datasets. EEG channel averaging allows for compression of the original multichannel EEG data and is used as an approach for the reduction of the dimensionality of the data. Using these two approaches the PSD features are calculated after the spectrum for the segments is obtained by performing DFT and calculating differences of the 16-45 Hz frequency bins for the spectrums of different signal segments. In the case where covariance features are used the covariance coefficients of the aforementioned frequency range are calculated for different signal frames. The use of the coefficients as features allows for a significant reduction of the obtained classification data.

For the experimental evaluation EEG data from the DEAP database is used. The assignment of the classes is performed only on the basis of the reported *Familiarity* rating for each stimulus. In this way a total of 5 classes are defined, ranging from "*Not familiar*" to "*Very familiar*". Using the feature extraction methods three sets of experimental data are created. The first dataset contains PSD difference features extracted from the EEG signals without channel averaging. The second feature extraction approach utilizes frame averaging. For the third approach the PSD covariance of the frames is calculated. The generated person specific datasets are used to determine the accuracy and relevance of the considered features. The experimental evaluation of the data is conducted using the WEKA machine learning toolbox and 3 classification algorithms are examined – kNN, rbf SVM and C4.5 Decision tree.

After the conducted evaluation highest mean classification accuracy of 99.5% was achieved using kNN classifier and PSD differences, calculated from all EEG channels. Overall, the highest classification accuracy was achieved using the PSD features, extracted from all channels of the EEG signals, followed by the average channel PSD features. The covariance coefficients demonstrate the lowest classification results with maximal mean classification accuracy of 80.1%.

[Г7.5] Feradov, F. N. (2021). EEG image features for classification of emotional states. Paper presented at the *2021 30th International Scientific Conference Electronics, ET 2021 - Proceedings*

The paper presents an examination of EEG image features designed for the purposes of emotion classification. The approach is based on processing multichannel EEG data and presenting brain activity as spatial spectrograms from which selected features can be extracted. Using the histograms of the obtained images statistical parameters indicating the distribution of elements, more specifically differences of percentile values are calculated and employed as features in emotion classification tasks.

During the initial stage of processing the EEG signals are filtered with a high pass filter with cut-off frequency of 10 Hz. The obtained filtered signals are separated into frames with fixed length of 1 second, with no overlap between subsequent frames. The spectral activity for the different frames is obtained through the use of DFT (Discrete Fourier Transform). This procedure is performed identically on all of the recorded channels. The obtained spectrograms for each frame are further transformed into monochrome images and the histograms of the obtained images are calculated. This approach is used due to the high compression of information which is achieved without omitting data for the states that are examined. From the histograms percentile values, reflecting the distribution of elements in the generated spectrograms, are calculated. The final features are obtained as the difference between different percentile values.

The presented research is carried out with data from the SEED database and the EEG data of each participant is split into three groups, in accordance with the ratings of the stimuli – "*positive*", "*neutral*" and "*negative*". The EEG recordings are processed and a total of six features are used in the experiments – the difference between the 98th and 80th, 82nd, 84th, 86th, 88th and 90th percentiles. As a result the processed EEG recording results in 6 feature vectors with length of 200 values, with each reflecting the activity in a given moment of the recording. After all of the recordings of a given participant are processed, the calculated feature vectors are combined into a single data structure with size of 270 x 200. Classification of the generated data sets is performed in the WEKA machine learning toolbox and 4 different classification algorithms are used – kNN, SVM with polynomial and rbf kernel and REPTree decision tree.

The examined features provide near perfect (>99%) classification accuracy for all the classifiers, with the exception of the cases where REPTree classifier is used (mean classification accuracy of 83.8 %). The observed high classification accuracy can be attributed to the specific information about the EEG signals, provided by the examined features. The calculation of the differences of percentiles of the histograms is an approach which provides a simple measurement for the intensity and amplitude of the brain activity. The differences in the percentiles of the histogram allow for the easy separation of cases where the measured brain activity has an equal intensity and distribution between all electrodes and cases where spikes of activity in certain areas are observed. Although the examined features demonstrate very high classification results for emotion detection they are not universally applicable for all EEG classification tasks. In cases where both classified states lead to similar patterns of activity – such as various cognitive tasks – the proposed features demonstrate unsatisfactory results.

[Г7.6] Feradov, F., Classification of Emotional States and Familiarity based on EEG Signals, Paper presented at *International Conference on Biomedical Innovations and Applications - BIA-2021*, Varna, Bulgaria, 2022 paper. #31

Emotional reactions and familiarity towards multimedia stimuli are closely connected and have a strong effect during tasks related to the classification of emotion and cognitive activity. The current study presents spectral activity-based EEG features for simultaneous classification of emotional states and level of familiarity towards multimedia stimuli. More specifically the classification is conducted using features based on the activity in different spectral bands of EEG signals.

The first step of the feature calculation procedure is the initial conditioning of the EEG signals. The procedure requires filtration of noises and artefact removal from the signals. The filtered signals are separated into frames with a fixed length, with no overlap between neighboring frames. A short-time Fourier transform (STFT) is performed on each generated signal frame and the obtained frame spectrums is separated into subsections with even sizes covering specific frequency bands. The mean spectral power for the defined frequency bands is calculated. The final features are obtained as the differences between the mean values for the spectral activity in different periods of the EEG signal.

For the experimental evaluation of the calculated features EEG recordings from the SEED database are utilized. The SEED database contains recordings of EEG activity from 15 participants who are presented with 15 short movie clips. Each participant is recorded three times in three separate sessions, held on different days. The currently presented experiments are designed to simultaneously classify emotional states and levels of familiarity towards multimedia stimuli. For that purpose, the EEG data provided for each participant is split into nine groups, depending on their emotional response class and the recording session. After assigning the classes to the recordings provided in the dataset, the examined features are extracted. The classification and evaluation of the obtained features are performed using the WEKA machine learning toolbox using three classification methods – kNN, Polynomial SVM, and C4.5 classification tree.

A total of four experimental setups are used to evaluate the examined emotion and familiarity classification approach. The examined features are extracted from the signal spectrum range of 10 – 100Hz, with four variations in the size of the frequency bins which are averaged – 5, 10, 15 and 20 Hz. The highest observed classification accuracy for all four signal processing approaches is achieved when the kNN classifier is used. Classification using an SVM classifier with a polynomial kernel yields the second-highest results while using a Decision tree classifier provided the lowest classification accuracy in the range of 70.3 to 73.2%. The only case in which a decrease in the mean classification accuracy - a total reduction of 11.1% - is observed with the increase in the range of the averaged spectral band is in the case where the SVM classifier is used.

The experimental results show that using the temporal differences of the mean values of the spectral frequency bands is an informative approach that allows for the classification of combinations of emotional states and familiarity. Furthermore, the conducted experimental evaluation has shown that the change of the range of the averaged spectral band has effects on the mean classification accuracy, indicating that the higher resolution in the analysis of the frequencies is important when both affective and cognitive activity is classified.

[Г7.7] Feradov, F., Features for Classification of Multimedia Stimuli from EEG Signals, Paper presented at *International Conference on Biomedical Innovations and Applications - BIA-2021*, Varna, Bulgaria, 2022, paper. #36

The rapid development of consumer electronics and multimedia devices has had a strong effect on the applications and use of EEG signals for tasks not specifically aimed toward medical applications. The presented paper examines a parameterization approach aimed towards the classification of multimedia stimuli from EEG channels. The proposed is approach based on wavelet decomposition of multichannel EEG signals and the detection of time-dependent locations with peaks in brain activity. The approach aims to create features which reflect the dynamic changes in the EEG signals and create a model of the reaction of the brain towards specific multimedia stimuli.

The feature extraction process of the proposed approach is conducted in following a four step signal processing procedure. During the first step the EEG signal is filtered and artefacts are removed. After pre-processing is completed discrete wavelet decomposition is applied, as it allows for the temporal examination and localization of different events associated with spikes in activity. The third step of the feature extraction procedure is conditioning of the obtained wavelet approximation. During this process the approximation is resampled by interpolation back to the original EEG size, after which a median filter is applied to its absolute value and, finally, it is scaled to the range of 0 to 1. In the last stage of the feature extraction process the obtained EEG activity approximation is scanned using synthetic signal *t* representing a peak in activity. The correlation coefficients for the EEG approximation and signal *t* are calculated and are used as features.

The obtained features are evaluated using a standard experimental protocol. The experimental setup is aimed at the classification of different multimedia stimuli from EEG recordings. For the experimental evaluation data from the DEAP database is used. After the feature extraction procedure is applied to the data of each one of the 32 participants included in the database the calculated features are combined into classification datasets. The evaluation is conducted using two experimental setups – a person-specific and a person-independent one. In the person-specific approach all of the features are calculated from the data of a specific participant. The person-independent datasets are obtained by combining a given number of person-specific data.

During the experimental evaluation of the generated feature sets four classification algorithms are employed – Linear discriminant analysis (LD), k-Nearest Neighbours (kNN), Decision tree (DT) and linear Support Vector Machine (SVM). The experiments are conducted using a 10-crossfold validation. The achieved mean classification is 96% for classification of stimuli from person-specific data. In the case where person-independent classification is conducted mean results of up to 94.9% are achieved. The conducted experimental evaluations demonstrated a general reduction in the classification accuracy with the increase of the diversity of participant data used for the formation of the datasets. The obtained results indicate that the proposed parameterization approach is applicable in cognition-based classification tasks. The utilized methodology demonstrates good parameterization capabilities in regards to the temporal localization of activity peaks in EEG signals. These patterns of activity provide sufficient information for the EEG based classification of multimedia stimuli.

[Indicator Г8] Scientific publications in non-indexed journals and proceedings.

[Г8.1] Markova V., Dicheva C., **Feradov F**., Kalinin Y. and Ganchev T., SLADE – Stress Level and Emotional State Assessment Database: Phase 1, *Computer Science and Technologies*, 2016, ISSN 1312-3335

The paper reports on the design and development of a new physiological signals database, referred to as SLADE, which aims to support research on stress level assessment and recognition of emotional states. The database consists of synchronized EEG, ECG, and GSR recordings. In the pilot phase of this project 10 healthy subjects were recorded, with an average length of the recordings of 60 minutes per person. The data collection protocol makes use of a set of 40 audio-video stimuli. These stimuli are one-minute excerpts selected from a set of musical clips of various genres.

The EEG signals were acquired by means of a 16-channel UltraCortex (Mark III) 3D-printed headset, which works with the Open BCI solution, an open-source brain-computer interface. The Open BCI board is built around a bio-sensing microcontroller that acquires 16-channel EEG, aggregates and wirelessly transmits all data to a laptop PC. The 3-lead ECG and the GSR sensing modules, which were purposely developed at the Sensor Network Lab., Technical University of Varna, were connected to a multichannel DAQ device USB 6009 of National Instruments that is connected to a laptop through a USB cable.

For the purpose of compatibility, the SLADE database was created by following a well-established experimental protocol. In brief, the protocol is based on recording EEG and other physiological data from participants who are watching short segments of musical videos – in our case one-minute excerpts of 40 videos of different musical genres. These stimuli were purposely selected to arouse emotions in the four quadrants of the valence-arousal space: low arousal – low valence; low valence – high arousal; high valence – low valence; high valence – high arousal. In total, fifteen volunteers took part in Phase 1 of the dataset recording project. All of them were young males -- between 20 and 25 years old. The bio-signals collected from the first five volunteers were used for calibration of equipment and refining the experimental setup and the recording protocol. The subsequent ten constitute the Phase 1 dataset outlined here. After the end of each audio-video stimuli, each participant filled in a self-assessment form, specifying his perceived levels of arousal, valence, and dominance. The valence scale ranges from happy/joyful (5) to unhappy/sad (1). The arousal scale varies from stimulated/exited (5) to calm/bored (1). The dominance scale ranges from dominant/empowered (5) to submissive/meek (1).

Conducted analysis of the scores shows that there are significant differences with regard to the ratings specified for each of the 40 stimuli. For instance, some of these stimuli, e.g. 5, 12, 18, and 37, elicit more pronounced emotional impacts. Specifically, the audio-video stimuli 18 falls into the low arousal / high valence quadrant and is characterized with a high mean value according to the ratings specified by participants. Even though the stimulus 18 was rated differently among the 10 participants, it can be accepted that it made them feel calm and happy.

In conclusion, we can summarize that the Phase 1 of implementation of the SLADE database was successful and the targeted outcomes were achieved. However, an in-depth evaluation of these preliminary results still needs to be performed before we proceed with the data collection in the next phases of this project.