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Transactions on Rough Sets VII

Commemorating the Life and Work of Zdzisław Pawlak, Part II

Springer

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Preface

Volume VII of the *Transactions on Rough Sets (TRS)* is a sequel to volume VI of the TRS. Both volumes commemorate the life and work of Zdzisław Pawlak (1926-2006)[1]. It is evident from the wide spectrum of contributions to these volumes that Zdzisław Pawlak's legacy is rich and varied. Prof. Pawlak's research contributions have had far-reaching implications inasmuch as his works have served as cornerstones in establishing new frontiers for scientific research in a number of fields.

From an early age, Zdzisław Pawlak devoted his life to scientific research. His pioneering work included research on modeling industrial processes, the design of computers, information retrieval, modeling conflict analysis and negotiation, genetic grammars and molecular computing. His research led to the introduction of knowledge representation systems during the early 1970s and the discovery of rough sets during the early 1980s. Added to that was Prof. Pawlak's lifelong interest in painting, photography and poetry. During his lifetime, he nurtured worldwide interest in approximation, approximate reasoning and rough set theory and its applications[2]. Evidence of the influence of Prof. Pawlak's work can be seen in the growth of rough-set literature that now includes over 4000 publications by more than 1600 authors in the rough set database[3] as well as the growth and maturity of the International Rough Set Society[4]. Moreover, numerous biographies of Zdzisław Pawlak have been published[5].

This volume of the TRS presents papers that reflect the profound influence of a number of research initiatives by Zdzisław Pawlak. In particular, it introduces a number of new advances in the foundations and applications of artificial intelligence, engineering, logic, mathematics, and science. These advances have significant implications in a number of research areas. In addition, it is evident from the papers included in this volume that rough set theory and its application form a very active research area worldwide. A total of 42 researchers from 13 countries are represented in this volume, namely, Australia, Canada, Germany, India, Italy, Japan, Poland, P.R. China, Sweden, Thailand, Taiwan, UK (Wales) and the USA. Evidence of the vigor, breadth and depth of research in the theory and applications of rough sets can be found in the articles in this volume.

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[1] Prof. Pawlak passed away on 7 April 2006.

[2] See, *e.g.*, Pawlak, Z., Skowron, A.: Rudiments of rough sets, *Information Sciences* 177 (2007) 3–27; Pawlak, Z., Skowron, A.: Rough sets: Some extensions, *Information Sciences* 177 (2007) 28–40; Pawlak, Z., Skowron, A.: Rough sets and Boolean reasoning, *Information Sciences* 177 (2007) 41–73.

[3] `http://rsds.wsiz.rzeszow.pl/rsds.php`

[4] `http://roughsets.home.pl/www/`

[5] See, *e.g.*, Peters, J.F. and Skowron, A., Zdzisław Pawlak: Life and Work. *Transactions on Rough Sets* V, LNCS 4100 (2006) 1-24. See, also, R. Słowiński, Obituary, Prof. Zdzisław Pawlak (1926-2006), *Fuzzy Sets and Systems* 157 (2006) 2419-2422.

Most of the contributions of this commemorative volume of the TRS are on an invitational basis and every paper has been refereed in the usual way. This special issue of the TRS contains 19 papers that explore a number of research streams that are either directly or indirectly related to research initiatives by Zdzisław Pawlak. These research streams are represented by papers on intelligent signal processing techniques (Andrzej Czyżewski), belief networks (Jerzy W. Grzymała-Busse, Zdzisław S. Hippe, Teresa Mroczek), relational attribute systems (Ivo Düntsch, Günther Gediga, Ewa Orłowska), dominance-based rough set approach (Salvatore Greco, Benedetto Matarazzo, Roman Słowiński), rough sets in bioinformatics (Torgeir R. Hvidsten, Jan Komorowski), selection of important attributes for medical diagnosis systems (Grzegorz Ilczuk, Alicja Wakulicz-Deja), rough clustering (Pawan Lingras), case-based reasoning classifiers (Yan Li, Simon Chi-Keung Shiu, Sankar Kumar Pal, James Nga-Kwok Liu), Web information gathering (Yuefeng Li, Ning Zhong), rough sets in pattern recognition (Sushmita Mitra, Haider Banka), possibilistic information (Michinori Nakata, Hiroshi Sakai), hybrid rough sets-population-based system (Puntip Pattaraintakorn, Nick Cercone), intelligent system for survival analysis based on hybrid rough sets (Puntip Pattaraintakorn, Nick Cercone, Kanlaya Naruedomkul), classifying remotely sensed images (B. Uma Shankar), rough feature selection (Qiang Shen), granulation in information security (Da-Wei Wang, Churn-Jung Liau, Tsan-sheng Hsu), definability and approximation (Yiyu Yao), audiovisual emotion recognition (Yong Yang, Guoyin Wang, Peijung Chen, Jian Zhou, Kun He).

The editors of this volume extend their hearty thanks to the following reviewers: Jan Bazan, Maciej Borkowski, Beata Konikowska, Bożena Kostek, Pawan Lingras, Son Nguyen, Wladysław Skarbek, Marcin Szczuka, Sheela Ramanna, Dominik Ślęzak, Jerzy Stefanowski, Piotr Synak, Dimiter Vakarelov, Hui Wang, Piotr Wasilewski, Marcin Wojnarski, Jakub Wróblewski, and Yiyu Yao.

This issue of the TRS has been made possible thanks to the laudable efforts of a great many generous persons and organizations. The editors and authors of this volume also extend an expression of gratitude to Alfred Hofmann, Ursula Barth, Christine Günther and the LNCS staff at Springer for their support in making this volume of the TRS possible. In addition, the editors extend their thanks to Marcin Szczuka for his consummate skill and care in the compilation of this volume.

December 2006

Victor Marek
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LNCS Transactions on Rough Sets

This journal subline has as its principal aim the fostering of professional exchanges between scientists and practitioners who are interested in the foundations and applications of rough sets. Topics include foundations and applications of rough sets as well as foundations and applications of hybrid methods combining rough sets with other approaches important for the development of intelligent systems.

The journal includes high-quality research articles accepted for publication on the basis of thorough peer reviews. Dissertations and monographs up to 250 pages that include new research results can also be considered as regular papers. Extended and revised versions of selected papers from conferences can also be included in regular or special issues of the journal.

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Speech Coding Employing Intelligent Signal Processing Techniques

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Abstract. The concepts and experiments presented are focused on modifications of an existing parametric speech coding algorithm (CELP) introduced in order to improve subjective speech quality in telephone connections. The perceptual coding to bit rate limiting was added and algorithms qualifying speech components to the categories of "voiced", "unvoiced", "transients" using rough sets were studied. The speech signal quality achieved with the proposed hybrid codec was compared to the quality offered by some standard speech codecs.

Keywords: CELP residual coding, hybrid codec architecture, perceptual speech coding, rough set decision algorithm.

1 Introduction

The majority of speech telecommunication systems in today's use offer a narrowband transmission, limited to about 200– 4000 Hz. The principal effect of band limiting is the degradation of intelligibility of speech occurring mostly due to the influence of upper band limiting to the perception of plosives and fricatives. Moreover, recognizing co-talkers is impeded because of the meaning of vocal tone band located in the range of low frequencies.

Typical applications of computer technologies in digital signal processing only rarely consider the opportunities of data processing with the use of methods which stem from artificial intelligence or soft computing. In the meantime the area of DSP (Digital Signal Processing) has an extensive demand for applications of intelligent signal processing because of unrepeatability and uncertainty of real-life signals and the lack of adequate mathematical models of signal production processes. That is why learning algorithms and data mining techniques are important to this kind of applications.

In most of the applications related to transmission of speech signal, parametric coding algorithms are used (CELP, ACELP, LD-CELP, etc.). These algorithms reduce bit-rate of the signal significantly, sacrificing quality of the signal to some degree. For many years, bit-rate and delay were the main criteria in speech codec assessment, while subjective signal quality, expressed using the mean opinion score (MOS) scale, was considered less important. Most of parametric speech

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codecs used in current applications provides signal quality from 3.2 to 4.0 in the MOS scale (where 5.0 means the best possible quality) [26].

The meaning of wideband speech is now recognized in some newer ITU-T standards. Two of them, called AMRWB and VMRWB, can be viewed as pure speech coding algorithms based on the ACELP technology. They do not provide, however, at least satisfactory quality of non-speech signals representation [19,24]. Therefore, an extended AMRWB+ codec was introduced to overcome this limitation. Unfortunately, as the AMRWB+ codec takes an advantage of hybrid ACELP/transform coding techniques, it introduces a coding delay up to 90 ms, thus in general it is not suitable for the real-time two-way communication. Accordingly, one can notice that there is still a need for A wideband, highquality, mid-delay speech codec with improved ability to encode non-speech signals.

Contrarily to coding techniques based on the speech production model, that is insufficient for more complex signals, the codec proposed in this paper employs the analysis technique for extracting sines, noise and transient parts of the signal. The analysis is supported by a soft computing algorithm. In the next step, each part of the entire signal is encoded using an adequate technique, including the perceptual criteria. It has to be mentioned that sines+residual model is widely used as a powerful tool for signal modification (e.g. pitch, time-scale) [20]. The sines+residual signal representation was also employed for efficient narrowband speech coding at about 8 kbps rate. Additionally, it was found that it is a robust method for coding both speech signals and mixed audio content [18,21,23]. Concerning this, it was also expected that extending the sines+residual model with transient selection module will further improve the signal representation accuracy. As the aim is to present the super-wideband signal to the listener, the spectrum components exceeding 7 kHz are reconstructed artificially in the proposed approach. It has to be mentioned that during some stages of encoding process the perceptual criterion was applied, allowing a reduction of the bit-rate requirements for the codec bit stream [5,22].

The main problem in the parametric approach to speech coding is how to encode transients, voiced and unvoiced signal components, efficiently. Encoding of transient states is especially important here, because an inappropriate encoding of transients may result in significantly decreased signal quality, Various parametric codecs use different approach to this problem, yet none of these approaches provide sufficiently accurate transient encoding, which is reflected in quality values (MOS). One of the concepts of the hybrid codec presented in this paper is extraction of transient, voiced and unvoiced components from the signal and using an appropriate approach for each of these groups. In the synthesis of musical instruments, the introduction of transient analysis and synthesis to the "sine and noise" model resulted in improved signal quality. Hence, it may be expected that using a similar "voiced-transient-unvoiced" approach to speech signal will provide an improvement of signal quality, as well. However, no research on this topic has been done so far by the author and his team of researchers.

The aim of the perceptual speech codec module is to improve further signal quality by incorporating the perceptual coding algorithm into the parametric codec. The calculation of the masking offset, playing a significant role in the masking threshold calculation based on the uncertainty measure can be also interpreted in terms of rough set theory [1]. That is because of a dependency occurring between the rough measure and the unpredictability measure. The noisy data processing is an evident example of making uncertain decisions, because Unpredictability Measure represents the margin of uncertainty while interpreting sound spectrum shape in terms of useful or useless components representation [14].

The novel approach to speech coding using the hybrid architecture is presented in the consecutive paragraphs of this paper. Advantages of parametric and perceptual coding methods are utilized together in order to create a speech coding algorithm assuring a better signal quality than in the traditional CELP parametric codec.

2 Voiced/Unvoiced Speech Selection Algorithms

Since the LP coding relies on a simple two-state model of speech production, each frame of the input signal is classified either as voiced or unvoiced. Usually, the classification is based on the observation that frames of voiced parts are strongly correlated with each other and have relatively higher energy than unvoiced parts [6]. This approach is also utilized in the engineered algorithm. However, an additional intelligent decision module is employed in order to ensure that frames classified as unvoiced will not contain transients.

The detector relies on three parameters which are calculated for every block of segmented signal $s[n_0,...,n_{N-1}]$ according to the following formulas [6,7,16]:

$$x_o = \frac{1}{2N} \sum_{n=1}^{N-1} \left| sgn\left(s\left[n\right]\right) - sgn\left(s\left[n-1\right]\right) \right| \tag{1}$$

$$x_1 = \frac{1}{N} \sum_{n=0}^{N-1} \left| s\left[n\right] \right| \tag{2}$$

$$x_2 = \max\left(\sum_{n=0}^{\frac{N}{2}-1} s\left[n\right] \cdot s\left[n + \frac{N}{2}\right] \right) \tag{3}$$

where: $s[n]$ – block of the signal, N – frame length.

The frame is classified as voiced if the following expression is true:

$$w_0 + \sum_{k=1}^{M} w_k \cdot x_{k-1} > 0 \tag{4}$$

where: w_k – elements of weighting vector, M– number of parameters.

The w_k elements of weighting vector were chosen in order to allow a proper frame classification for different speech samples. Since the detector does not take into account any information about the previous classification results, the voiced/unvoiced decision may change instantly from one frame to another when some special conditions occur. Thus, an appropriate hysteresis function was utilized previously [16] in order to prevent undesirable state changes of the detector. It has to be mentioned that not only pure-voiced frames but also frames containing transients are classified into the voiced part of the speech signal. Instead of the decision term (4) a soft computing decision algorithm was also employed to define the current frame as voiced or unvoiced. This algorithm based on the rough set approach uses an automatically reduced set of attribute values and learned rough rules. The conditional attributes are represented by: $x_0=\{0,1\}$; $x_1=\{$low, medium, high$\}$; $x_2=\{$low, medium, high$\}$. The decision attribute is binary d $=\{$voiced, unvoiced$\}$.

The rough set algorithm implemented earlier by R. Krolikowski was utilized [17]. The elaborated rule induction algorithm is based on the rough set methodology. Since the basic rough operators (the partition of a universe into classes of equivalence, C-lower approximation of X and calculation of a positive region) can be performed more efficiently when objects are ordered, the algorithm often executes sorting of all objects with respect to a set of attributes. Reducing of values of attributes requires that all combinations of the conditional attributes must be analyzed. In general case, the decision table should be sorted as many times as is the number of all these combinations. Therefore, in every set of attributes A ($A \subseteq C$), a subset of the conditional attributes C should be exploited as many times as possible. The algorithm splits the decision table T into two tables: consisting of only certain rules (T_{CR}) and of only uncertain rules (T_{UR}). For them both, there is additional information associated with every object in them. The information concerns the minimal set of indispensable attributes and the rough measure μ_{RS}. The latter case is applied only for uncertain rules. The elaborated algorithm consists of the following main group of modules:

a) Master procedure of all procedures related to the rough set-based induction algorithm

– **procedure** RS_algorithm

It is assumed that a decision table is fed to the procedure either at a call or supplied during its execution. By analogy, the procedure returns a table with generated rules.

b) Initial procedures

– **procedure** preprocessing

The procedure prepares 2 tables of certain T_{CR} and uncertain rules T_{UR}. In addition, it computes the set of concepts V with respect to the set of attributes D.

– **procedure** generate_rules(C : set_of_attributes)

Input: C - the set of the conditional attributes

The procedure is a master procedure of all those procedures and functions which task is to generate rules by removing superfluous values of attributes. At the end, these values are replaced by 'do not care' value. However, the procedure affects the tables T_{CR} and T_{UR} in an implicit way.

– **procedure** postprocessing

The procedure prepares the output table of generated rules T in such a way that a rule could be accessed in at most $|C| \cdot \log_2 N$ comparisons, where N is the number of objects in T.

c) Procedures preserving the proper depth of the analysis of the conditional attributes

– **procedure** P (C, A : set_of_attributes)

Input: C - the set of the conditional attributes,
A - an arbitrary set of attributes, where $A \subseteq C$
Output: potentially modified auxiliary data associated with the tables T_{CR} , T_{UR}

The procedure provides the proper depth of the analysis of all combinations of the conditional attribute set C and is executed recursively.

– **procedure** _P (A : set_of_attributes; *depth* : integer)

Input: A - an arbitrary set of conditional attributes,
depth - depth of recursions,
Output: potentially modified auxiliary data associated with the tables T_{CR} , T_{UR}

Similarly to the procedure P(), this procedure provides the proper order of the analysis of all combinations of the conditional attribute set C. It contributes to a further recurrent processing of the conditional attributes and is similar to P().

– **procedure** left (A : set_of_attributes; *depth* : integer)

Input: A - an arbitrary set of conditional attributes,
depth - depth of recursions,
Output: potentially modified auxiliary data associated with the tables T_{CR} , T_{UR}

The procedure is strictly related to the proper depth of the analysis of the conditions and concerns recurrent processing. The execution of the procedure enables the analysis of some subsets of the attributes without sorting the table.

d) Procedures eliminating superfluous values of attributes in certain and uncertain rules

– **function** process_certain_rules (A : set_of_attributes): set_of_sets_of_objects

Input: A - an arbitrary set of conditional attributes,
Output: Z - set of sets of objects belonging to the same equivalence class, potentially modified auxiliary data associated with the table T_{CR}

The function performs all necessary operations in order to reduce values of attributes. In consequence, it may cause a removal of an attribute. The procedure affects only certain rules. The output value $Z = U_{CR}/IND(A)$ is returned so that the procedure **process_uncertain_rules** doesn't need to compute the partition $U_{CR}/IND(A)$.

– **procedure** process_uncertain_rules
(Z : set_of_sets_of_objects;A : set_of_attributes)

Input: Z - set equivalence classes for the tableT_{CR} ($U_{CR}/IND(A)$) ,
A - an arbitrary set of conditional attributes
Output: potentially modified auxiliary data associated with the table T_{UR}

The procedure calculates the rough measure for each object of the decision table T_{UR} (uncertain rules) and for each combination of attributes. The largest values of the measure are stored.

e) Functions which are related to the basic rough set operators

– **function** U_IND (T : table; A : set_of_attributes) : set_of_sets_of_objects

Input: T - a decision table,
A - an arbitrary set of attributes,
Output: a set of objects belonging to the same equivalence class

The function parts the universe U (table T) into classes of equivalence $U/IND(A)$ according to indiscernibility relation with respect to a set of attributes A.

– **function** _CX (T : table; C, X : set_of_attributes) : set_of_objects

Input: T - a decision table,
C, X - arbitrary sets of attributes,
Output: a set of objects in T which belong to the C-lower approximation of the set X

The function computes the C-lower approximation of X.

– **function** POS_REG (T : table; A1, A2 : set_of_attributes) : set_of_objects