Advances in Intelligent Systems and Computing 1236

Zuzana Kubincová · Loreto Lancia ·
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Methodologies and Intelligent Systems for Technology Enhanced Learning, 10th International Conference. Workshops

Volume 2

Springer

Advances in Intelligent Systems and Computing

Volume 1236

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ISSN 2194-5357 ISSN 2194-5365 (electronic)
Advances in Intelligent Systems and Computing
ISBN 978-3-030-52286-5 ISBN 978-3-030-52287-2 (eBook)
https://doi.org/10.1007/978-3-030-52287-2

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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Construction of Fuzzy-Classification Expert System in Cerebral Palsy for Learning Performance Facilitation

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Abstract. The paper presents a novel method and conceptual architecture for implementation of fuzzy-classification expert system in the domain of rehabilitation methods for cerebral palsy. The expert system includes two blocks: Fuzzy block utilizing fuzzy algorithms for multi-criteria decision making and Machine learning block based on algorithms for tree classification and KMeans clustering. The proposed solution is designed for facilitation the learning performance of university students as well as for professionals who have to make decisions in the area of cerebral palsy and corresponding rehabilitation methods.

Keywords: Expert system · Learning performance · Cerebral palsy · Rehabilitation methods · Fuzzy theory · Machine learning

1 Introduction

The term "cerebral palsy" relates to permanent developmental disorders that occurred early in human biological development or in early childhood. These developmental disorders primarily refer to conditions of abnormal gross and fine motor functioning. It also may happen that children do not have proper spatial relationships and notion of themselves – they are not able to show where is his head, what is his left or right arm or leg, etc. Therapy of motor skill disorders in children is long-termed and should start as early as possible. Since cerebral palsy patients significantly differ among themselves, therapy should be adapted to a particular child. However, therapy may also be tiresome, uncomfortable or even painful for the child. Therefore, it is essential that the child is motivated to undergo therapy, which is a challenging therapeutic task.

Z. Kubincová et al. (Eds.): MIS4TEL 2020, AISC 1236, pp. 5–14, 2021.
https://doi.org/10.1007/978-3-030-52287-2_1

Recent research in the field of robot-assisted therapy for children with cerebral palsy suggests that a robotic system has a primary role of a facilitator – it may increase motivation and trigger social interactions between the children and the therapist.

It is a hot topic where researchers are developing a prototypical robotic system intended to be used as an assistive tool in therapy for children with cerebral palsy. To be used in such application robot must be able to fulfill some basic requirements: it has to be able to demonstrate requested exercises, its appearance should be attractive to children and it should be able to communicate (verbal and non-verbal) with patients. However, in contrast to other approaches, Prof. Branislav Borovac introduced a conceptual novelty: the robot's capacity to engage in a natural language dialogue may be of significant clinical benefit [1]. The anticipated benefit of the conversational robot is to support the therapist to conduct specific therapeutic exercises and to contribute to establishing affective attachment of the child to the robot. Dr. & A/Prof. Zhenli Lu et al. propose a training system for cerebral palsy rehabilitation that is developed on the human-computer interaction principles (Fig. 1) [2].

Fig. 1. Technical architecture of speech recognition based expert system in robotic assistant rehabilitation of cerebral palsy

So, the aim of this paper is to present a novel approach for expert system construction based on fuzzy theory and machine learning algorithms for educational purposes. It includes knowledge about rehabilitation methods suitable for applying at different types of cerebral palsy and it is a preliminary step for development of a more complex expert system for usage by therapists and patients.

2 The Expert Systems: State-of-the-Art

The term expert system is related to development of interactive software that collects expert and users knowledge in a given domain and emulates the human ability of decision making and problem solving. It could be driven by a pool of cases or based on a set of rules that together with the knowledge expert domain leads to the appropriate inference. Different techniques and machine learning algorithms are utilized for simulation the individual thinking, group brainstorming, reasoning and concluding.

In this section the expert systems are examined according to three criteria: (1) the domain area that is medicine and a very concrete topic on rehabilitation methods for cerebral palsy; (2) the used artificial intelligence methods for expert systems realization; (3) the utilization purpose that is focused on usage in educational settings.

2.1 Expert Systems in Medicine and Cerebral Palsy

An expert system for medical diagnostics of cerebral palsy is proposed by Borgohain et al. [3]. It works with determined rules and inferences are patients' diagnose according to the input symptoms and also classification of cerebral palsy in three groups: mild, moderate and severe. Its development is based on JESS (Java Expert System Shell). Another expert system for evaluating the patients with cerebral palsy and giving an advice about the suitable wheel chairs and devices for body support is created by Ni et al. [4]. It consists of knowledge base regarding the evaluation of seating and positioning, a set of rules, inference engine with guidelines pointing out the assistive technologies and specifications with seating/positioning devices, module with the authors' research in this topic and friendly and interactive user interface. A beginning step for implementation of intelligent expert system is done by Zammouri et al. who assess different reeducative therapies that could be applied to the children with cognitive difficulties [5]. Their work is focused on brain-computer interface for evaluation the brain workload during performance of a cognitive activity. A rule-based expert system for diagnosing patients with heart diseases and prescription of suitable treatments is proposed by Soltan et al. [6]. This medical expert system is developed through Visual Prolog.

2.2 Artificial Intelligence Methods in Expert Systems

A survey regarding expert systems in medicine that utilize artificial intelligence methods is performed by Singla et al. [7]. This work shows that medical expert systems are developed with purposes of patients' diagnostics, for giving advices concerning treatment and therapy, for producing guidelines for patients and doctors, and for educational training. The main technologies behind their implementations are pointed out as: fuzzy logic, Artificial Neural Networks and neuro-fuzzy approach. Another review done by Sheikhtaheri et al. reports that expert systems for clinical purposes are focused on: quality improvement of first aid, disease prediction, disease identification, diagnosing, therapy suggestion, giving advice, disease classification and their realization is driven by fuzzy theory, Artificial Neural Networks, support vector machine, Naïve Bayes classifier, Wavelet neural network [8]. An implemented variant of expert system for recognition of cerebral palsy at babies and small children and prediction for their future suffering is presented by Ojo et al. [9]. The input variables are related to the motor skills and output is possibility for cerebral palsy development. It is realized through applying Fuzzy theory and Fuzzy logic in MATHLAB. Another medical expert system based on Fuzzy logic, data mining techniques and machine learning algorithms is created in support of decision making and information delivery regarding diagnosis of vertebral diseases and appropriate treatment [10]. Its software platform is developed with functionality for knowledge sharing among doctors and patients through chat, forum and video and also its knowledge base could be extended with additional modules gathering knowledge for a wide variety of hospital services. Advantages of creation hybrid expert systems based on Fuzzy logic and Artificial Neural Networks in context of speech therapy are revealed in [11]. Such expert systems possess typical characteristics like pointing out the personalized disease treatment and giving expert opinion, but also possibility for self-learning.

2.3 Expert Systems for Educational Purposes

A review regarding the usage of expert systems in educational settings is done by Supriyanto et al. who outline the main purposes that we classify in the following groups: (1) for improvement teaching and learning – students characteristics analysis, student performance analysis and prediction, evaluation of student competency, realization of personalized learning, evaluation of teaching efficiency; (2) for improvement the educational process at all - eLearning evaluation, evaluation of requirements for technical education, evaluation of education, improvement the quality of learning lesson plans, giving an academic advice, academic programs evaluation, evaluation of master level criteria; (3) in support of librarians [12]. The main didactical concepts behind development of an expert system for purpose of mathematics teaching are presented by Salekhova et al. [13]. A new module of expert system is introduced Concept-Effect-Relationship that contains the relationship among subjects and it is used for providing individual educational strategy to every learner. The main aim of this expert system is to increase the effectiveness of the teachers' activities. The enhancement of students' learning is achieved through usage of an expert system in the database course that contains hard concepts for understanding [14]. The students are supported through immediate feedback and corrections when they have to decide a problem. Another expert system is developed to predict students' performance during the computer science course [15]. The input variables are related to information for students – their attitudes, study habits and ways for preparation and the output is the predicted outcome.

3 Expert System Construction

The expert system includes knowledge about the cerebral palsy (CP) types: Spastic, Athetoid, Ataxic and Mixed with their typical symptoms and rehabilitation methods

(RMs) for cerebral palsy. Six experts from China and Bulgaria (three academic professionals, one expert is professor and neurologist and two experts are doctors-neurologists) were asked to vote the importance of 13 rehabilitation methods that are classified in two groups: approaches without using any equipment (8 RMs) and approaches with using equipment for each type cerebral palsy (5 RMs). The goal is to select suitable RMs for a given CP type. The conceptual architecture of the constructed expert system is presented on Fig. 2. Experts and scientific papers are reliable information sources for knowledge base building. The collected knowledge in the domain of rehabilitation methods for cerebral palsy is used for decision making or problems solving by reasoning through two types of inference engines: fuzzy inference block and machine learning block. Fuzzy inference block is constructed on FuzzyTOPSISLinear algorithm for group decision making proposed by Chen [16] and FuzzyWASPAS method for alternatives ranking presented by Turskis et al. [17]. The ground of the both methods is creation of aggregated fuzzy decision matrix $\tilde{D}$ with m alternatives and n attributes:

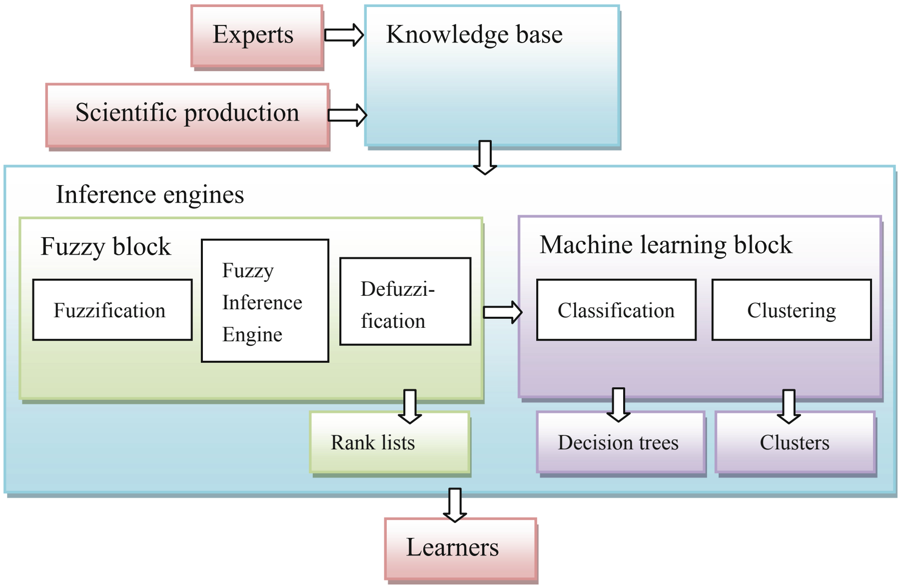


Fig. 2. Conceptual architecture of constructed expert system

$$\tilde{D} = \begin{vmatrix} \tilde{d}_{11} \ldots \tilde{d}_{1j} \ldots \tilde{d}_{1n} \\ \tilde{d}_{21} \ldots \tilde{d}_{2j} \ldots \tilde{d}_{2n} \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ \tilde{d}_{m1} \ldots \tilde{d}_{mj} \ldots \tilde{d}_{mn} \end{vmatrix} \quad (1)$$

The fuzzy decision matrix contains the aggregated experts' vote that is in a 5-Likert scale from **1**-this RM is **not important** for this type of CP to this RM is **very important** for a given CP type, expressed in linguistic variables and fuzzy triangular numbers. Table 1 includes input data in linguistic variables before the experts 'vote aggregation. Table 2 summarizes the experts' opinion concerning the importance of every rehabilitation method for each cerebral palsy type.

Table 1. Rating scale and the corresponding triangular fuzzy numbers

Likert scale range	Meaning	Linguistic variable	Triangular fuzzy numbers
1	Not important	NI	(0,1,3)
2	Slightly important	SI	(1,3,5)
3	Moderately important	MI	(3,5,7)
4	Important	I	(5,7,9)
5	Very important	VI	(7,9,10)

Linguistic variables and triangular fuzzy numbers concerning the severity level are as follows: mild (M) – (0.1,0.3,0.5), moderate (MO) – (0.3,0.5,0.7), severe (S) – (0.5,0.7,0.9). The experts' opinion related to the severity level of each type CP is summarized in Table 3.

Then, the experts' vote aggregation is performed for each RM in fuzzy numbers and the fuzzy aggregated decision matrix is constructed and normalized. The severity level of each type CP according to experts is taken as bases for forming the group weights and for building the weighted normalized fuzzy decision matrix. The fuzzy numbers (1,1,1) and (0,0,0) are defined as fuzzy positive and fuzzy negative ideal solutions and the distance from each RM to them is calculated. The closeness coefficients for each RM are calculated that are used for ranking list creation.

Machine learning block uses all data from Tables 1, 2, 3 and from the Fuzzy block to analyze them with aim to prepare further classification and clustering of RMs according to the CP types. As data mining algorithm J48 is applied for building the pruned classification tree that is suitable for decision making support [18]. The algorithm SimpleKMeans is used for RMs clusters calculation, because of its proven effectiveness at solving clustering problems.

4 The Expert System Verification

The working capacity of the Fuzzy block from the proposed expert system is verified through usage of R software environment and running FuzzyMCDM package [19] with FuzzyTOPSISLinear and FuzzyMMOORA functions for realization of Multi-Criteria Decision Making algorithms as it is shown on Fig. 3.

The working capacity of the machine learning block is verified through usage of Weka software [20] and some of integrated machine learning algorithms for data classification and clustering (Fig. 4).

Table 2. Experts rating vote regarding the importance of every rehabilitation method for each cerebral palsy type

CP type	RM	Expert1	Expert2	Expert3	Expert4	Expert5	Expert6
Spastic	RM1	VI	I	I	VI	VI	VI
	RM2	I	I	I	VI	VI	VI
	RM3	VI	I	VI	VI	VI	VI
	RM4	MI	I	MI	I	I	VI
	RM5	I	I	I	VI	I	SI
	RM6	I	I	I	VI	I	VI
	RM7	MI	MI	MI	VI	I	VI
	RM8	MI	MI	MI	VI	I	SI
Athetoid	RM1	I	I	I	VI	VI	SI
	RM2	I	I	I	I	VI	VI
	RM3	I	I	I	VI	I	I
	RM4	I	I	I	VI	VI	MI
	RM5	I	I	I	VI	I	MI
	RM6	MI	I	I	VI	I	VI
	RM7	I	I	I	VI	I	VI
	RM8	MI	MI	MI	VI	I	SI
Ataxic	RM1	I	I	VI	VI	VI	VI
	RM2	I	I	I	I	VI	VI
	RM3	I	I	I	VI	I	VI
	RM4	MI	MI	MI	VI	MI	I
	RM5	I	I	I	VI	MI	SI
	RM6	MI	MI	MI	VI	I	SI
	RM7	I	I	I	VI	I	SI
	RM8	MI	I	MI	VI	I	SI
Mixed	RM1	VI	VI	I	VI	VI	VI
	RM2	VI	VI	VI	VI	VI	VI
	RM3	VI	VI	VI	VI	VI	VI
	RM4	I	I	I	VI	VI	VI
	RM5	MI	MI	MI	VI	I	VI
	RM6	I	I	I	VI	I	VI
	RM7	I	I	VI	VI	I	VI
	RM8	I	I	I	VI	I	SI

Table 3. The severity level of different CP types

	Expert1	Expert2	Expert3	Expert4	Expert5	Expert6
Spastic	M	MO	M	M	MO	M
Athetoid	MO	S	MO	MO	MO	MO
Ataxic	S	S	S	MO	S	S
Mixed	MO	MO	S	MO	S	MO

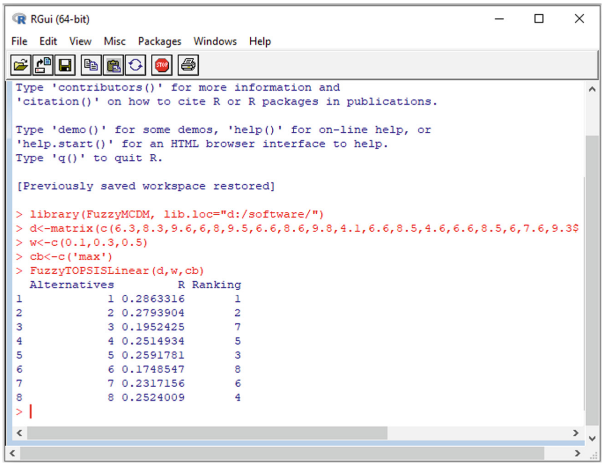
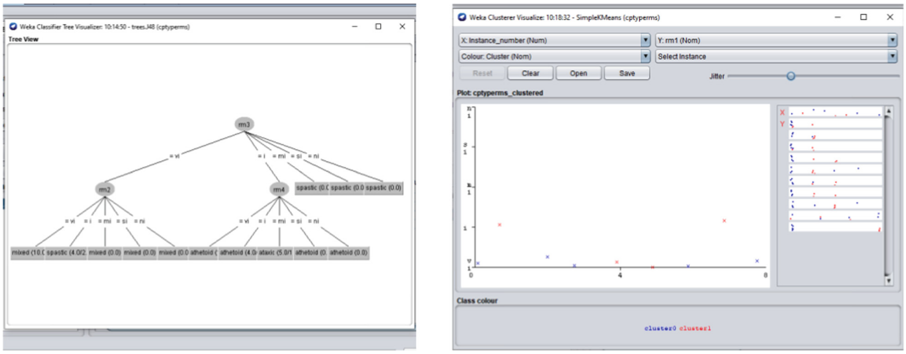


Fig. 3. The working capacity verification of the Fuzzy block



a). J48 algoritm for pruned decision tree construction

b). SimpleKMeans algorithm for clustering

Fig. 4. The working capacity verification of the machine learning block

5 Conclusions

IR (Intelligent Robotics) and HRI (Human Robot Interaction) related technologies are essential for expert system development, especially in the application of cerebral palsy rehabilitation. The novel method and conceptual architecture for implementation of fuzzy-classification expert system in the domain of rehabilitation methods for cerebral palsy are presented. Fuzzy block utilizing fuzzy algorithms for multi-criteria decision making and Machine learning block based on algorithms for tree classification and SimpleKMeans clustering are adopted to develop the expert system. Using the data by the surveying process and examined scientific production, the proposed solution designed for facilitation the learning performance of students, provided the construction of current expert system. The results of this work can give much help for the design of intelligent expert system for robotic assistant system in cerebral palsy rehabilitation.

Acknowledgments. The authors would like to thank the Research and Development Sector at the Technical University of Sofia for the financial support.

The previous work is funded by project of the 3rd Regular Session of the China-Serbia Inter-Governmental Scientific and Technical Cooperation Committee, project title “Study of human-robot interaction - Use of robot as assistive technology for cerebral palsy rehabilitation”; and the 12th Regular Session of the China-Slovenia Inter-Governmental Scientific and Technical Cooperation Committee, project title “Study on Key Intelligent Control Technology and Method of Robot Assistant System for Cerebral Palsy Rehabilitation”.

The authors express their deep gratitude to all participants in the surveying process for the priceless engagement and the quick response. Special thanks to Prof. Dr. L. Haralanov, Head of the NCH Nervous Diseases Clinic, Dr V. Damyanov, Vice Head of 8 DCC, Senior Assist. Prof. O. Boyanova, Medical University-Sofia, Prof. Branislav Borovac, Department of Industrial Engineering and Management, Faculty of Technical Sciences, University of Novi Sad, Serbia; Prof. Marjan Mernik, Faculty of Electrical Engineering and Computer Science, University of Maribor, Slovenia; Prof. Yan Liu, Yu Zhao, Zhipeng Ma, Hong Wang and Changkao Shan with Changshu Institute of Technology, Xuanlin Shen, Head of Department of Rehabilitation Medicine, Changshu No. 2 People Hospital, P.R. China; and Dr. & A/Prof. Jun Liu with Faculty of Biomedical Engineering & Instrument Science, Zhejiang University, P.R. China for the enthusiastic support in the surveying process.

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