REVIEW

under the procedure for acquisition of the educational and scientific degree "Doctor"

by candidate **Kristin Ilieva Aleksandrova**,

of the PhD Thesis entitled: "Semantic Technologies in eHealth" (Application of Machine Learning Technologies in Supporting Independent Living of the Elderly and Disadvantaged),

In the Scientific field: **4. Natural Sciences, Mathematics and Informatics**

Professional field: **4.6. Informatics and Computer Sciences**

Doctoral program "**Information systems - Knowledge-based systems**",

Department **„Computer Informatics"**

Faculty of Mathematics and Informatics (FMI),

Sofia University "St. Kliment Ohridski" (SU)

The review has been prepared by: **by Prof. Daniela Ananieva Orozova, DSc,** Trakia University, as a member of the scientific jury for the defense of this PhD thesis according to Order № РД-38-199/26.04.2024 of the Rector of the Sofia University. The presented set of materials is in accordance with the regulations on the terms and conditions for acquiring scientific degrees and holding academic positions in SU "St. Kliment Ohridski" and includes the following documents: Application from Kristin Alexandrova to the head of the department to open a procedure for the defense of a dissertation work; Dissertation in English, Abstracts in Bulgarian and in English; Statement of Authorship; Certificate of fulfillment of the minimum national requirements; Reference to Scopus publications; Report from the research supervisor on the readiness of the doctoral student; StrikePlagiarism Report, Protocol for verification of the originality of a dissertation work and Opinion of the research supervisor; List of publications; Enrollment order; Certificate of study as a part-time doctoral student at the FMI of the SU; Dismissal order for the doctoral student; Internal review by Prof. Tsunizhev; Minutes from the departmental council, for preliminary discussion of the dissertation work; Diplomas for completed bachelor's and master's degree studies; Autobiography; Reference from the Information System - Authors, Files of the two scientific publications on the topic of the dissertation work.

1. **General characteristics of the dissertation thesis and the presented materials**

The author of the dissertation is **Kristin Ilieva Aleksandrova** – a Ph.D student in part-time education at the department "Computer Informatics" of the Faculty of Mathematics and Informatics at the Sofia University "St. Kliment Ohridski", with supervisor Prof. Maria Nisheva-Pavlova, Ph.D.

Kristin Aleksandrova's dissertation on "Semantic Technologies in eHealth" (Application of Machine Learning Technologies in Supporting Independent Living of the Elderly and Disadvantaged) is 181 pages long (main text and appendices). The text is structured in an introduction, seven chapters, conclusion, bibliography and three appendices. The text includes 66 figures and 12 tables. The text would win if a glossary with explanations of the main terms and abbreviations is attached.

The work first addresses gaps identified by previous research papers looking at general-purpose ambient assisted living systems, referred to as AAL (Ambient Assisted Living) systems, as a sustainable way to ensure data protection and security in a growing system. These are factors that prevent the widespread distribution and use of this type of system. The functional requirements of such an AAL system, compliant with the requirements of the General Data Protection Regulation (GDPR), have been identified. By reusing modern middleware available and supported on open source platforms, a system prototype is created. The stream of data and events from the available sensors and smart devices, about the daily activities of the monitored person, is used to train models based on neural networks and associative rules. Their predictions and inferences allow a user caring for the person monitored by the system to understand the signals and ignore false results.

On page 10 of the dissertation, three research questions are defined and based on them the following hypothesis is formulated: "We can reuse open-source smart home middleware software to create a cost- and data privacy-aware AAL system, extend it with machine learning algorithms in a useful manner and prove that association rule mining (ARM) algorithms can be used for human behavioural recognition and they would be the better choice compared to standard outlier detection approaches for an AAL system as they are overall cheaper, easier to conform to data privacy regulations and they have explainable results".

The goal of this thesis is to prove the hypothesis as a whole and in its derivative parts by answering the defined research questions.

In **chapter 1** *"Introduction"* the history and actuality of the problem is presented and the necessity of conducting the research is justified. The research questions, hypothesis and objective of the dissertation work are defined.

In **chapter 2** *"Literature Reviewe"* a review of assisted living systems from the environment (AAL systems) was made. First, they classified types of systems based on their functionality (smart homes, intelligent assistants, portable and robotic assistance systems). Next is a review of AAL systems based on the technologies used (RFID and NFC technologies for unique identification and data exchange with radio waves, wireless sensor networks, portable sensors and other technologies). The most common machine learning algorithms for detecting anomalies and predicting human behavior are briefly presented.

In **chapter 3** *"Concept of the AAL Systeme"* a brief definition of the concept of the AAL system and the personality of the user is given, which is the basis for the creation of the prototype and expectations for the system. It evaluates already publicly available datasets that simulate the user's personality closely enough and can be used to train and evaluate machine learning methods.

In **chapter 4** *"System architecture and implementation"* a first version of the prototype based on the selected OpenRemote software is presented. An extension of the system architecture with a machine learning algorithm is proposed. The process of prototyping an AAL system that supports the performance of daily activities of the elderly using personalized sensors and a combination of rules is examined so that the system is tailored to the person for whom it is intended.

In **chapter 5** *"GDPR Requirements and compliance"* looks in detail at the possibilities of applying the general data protection regulation when building an AAL system that aims to combine non-intrusive data collection for users with machine learning algorithms to extract information about the physical and mental condition of the person cared for by the system. 15 requirements for the prototype of the AAL system and its behavior are derived. This enables quantitative measurement of GDPR compliance and data privacy protection.

In **chapter 6** *"Behavioural predictions"* an approach to applying different machine learning algorithms that create behavioral models is presented. These models are trained from a standard data set containing various activities of daily life, and can distinguish a certain person's normal stereotyped behavior or deviation from expected behavior. Two main approaches are applied and evaluated to the problem: neural networks (the two algorithms Autoencoders and LSTM) and algorithms for extracting associative rules (Apriori and FPGrowth) in the analysis of human behavior. Fifteen datasets from the CASAS collection were used to compare the approaches and performance of the four algorithms.

In **chapter 7** *„Conclusion"* a discussion is made on the research questions, the contributions received are noted and perspectives for future development of the subject are formulated.

Additional materials and references related to the research conducted are given in **three appendices**.

The analysis of the current state of scientific research in the field and the literature review made in the 2nd chapter, the large number of literary sources studied, as well as the conclusions drawn give me reason to conclude that the doctoral student has a thorough knowledge of the problems related to application of machine learning technologies in order to support the lives of elderly and disadvantaged people. A system is proposed that can find wide application due to the possibilities of real use, customization, low cost of maintenance and compliance with the principles of privacy and security of user data.

The research carried out in the dissertation work requires in-depth knowledge and scientific and practical qualifications, which its author undoubtedly possesses. This is evident from the ease with which the doctoral student argues and presents the main theses in the individual chapters of the dissertation and from the publications presented.

2. Short CV and personal impressions of the candidate

Kristin Aleksandrova completed her secondary education at the "Geo Milev" Science and Mathematics High School, Stara Zagora in 2013. Then, from 2013 to 2017, she completed her bachelor's degree at the "St. Kliment Ohridski", Faculty of Mathematics and Informatics, majoring in Computer Science. Since 2019, she has a master's degree, majoring in Artificial Intelligence, at the Faculty of Mathematics and Informatics of the Sofia University "St. Kliment Ohridski". From 2020, Kristin Alexandrova worked as a product manager at SAP SE from 2022 until now, and before that at SAP Labs Bulgaria EOOD.

She works as a part-time assistant at the Faculty of Mathematics and Informatics of the University of St. Kliment Ohridski" from 2014 to 2017 and conducts exercises in the disciplines: "Introduction to Programming", "Object Oriented Programming" and "Data Structures and Programming".

I do not know the candidate personally. From the published materials and submitted documents, my impressions of Kristin Aleksandrova are entirely positive.

3. **Content analysis of the scientific and applied achievements of the candidate, contained in the presented PhD thesis and the publications to it, included in the procedure**

I accept the main results and contributions indicated by the Ph.D. student on pages 155 - 156 of the dissertation. The contributions have a scientific, scientifically applied, and applied character.

An analytical overview of the state in the field of AAL systems has been made. The functional requirements that the AAL system must fulfill to ensure data privacy are analyzed and summarized. A methodology has been developed to create an AAL system with general application.

Mods are machine learning algorithms designed to recognize patterns in human behavior. An optimized implementation of the Apriori algorithm was created, which provides faster and equally accurate results compared to the FPGrowth algorithm for behavioral pattern recognition. A method is proposed to transform time-series recoded activities into labeled daily transactions for rule generation.

A comparison of the performance, accuracy and applicability of the proposed AAL neural network system and associative rule extraction algorithms is made. Experiments have been conducted that lead to the conclusion that associative rule extraction algorithms are more cost-effective and easier to maintain when applied to an AAL system for predicting behavioral patterns.

An AAL system is proposed that uses existing sensors and devices, integrated with machine learning algorithms that ensures compliance with data privacy and operates as a containerized solution in an isolated network.

A concept and requirements for AAL systems are created, focusing on total cost of implementation, long-term support and costs.

A prototype of an AAL system augmented with machine learning models has been implemented, which recognizes stereotyped behavior based on the data collected by the system and fulfills the functional requirements of a GDPR compliant system.

4. **Approbation of the results**

The results of the dissertation research are presented in 2 publications in peer-reviewed publications: reports from international scientific conferences in 2021 and 2022, indexed in the scientific database Scopus, with SJR. The publications are in English. Each of the two publications carries 30 points and exceeds the requirements of the Development of Academic Staff Act in the Republic of Bulgaria, the Rules for its Implementation and the corresponding Rules at the Sofia University "St. Kliment Ohridski" for acquisition by the candidate of educational and scientific

degree "Doctor". Additionally, a reference is provided for one more publication that has been submitted for review. The three publications are self-contained.

A good impression is made by the volume and depth of the publications, which comprehensively reflect the main aspects of the issues considered in the dissertation.

After a detailed review of the presented scientific works, I found that:

a) the scientific works meet the minimum national requirements (under Art. 2b, para. 2 and 3 of ADASRB*) and respectively to the additional requirements of Sofia University "St. Kliment Ohridski" for acquiring the educational and scientific degree "Doctor" in the scientific field and professional field of the procedure;

b) The results presented by the candidate in the dissertation work and scientific works to it do not repeat such from previous procedures for acquiring a scientific title and academic position;

c) There is no plagiarism proven in the legally established order in the submitted dissertation work and scientific papers under this procedure.

5. Qualities of the abstract

The Bulgarian and English abstracts correctly present the results and the content of the dissertation. Chapter 2 and Chapter 3 of the dissertation are not presented in the abstract, due to their overview nature.

6. Critical notes and recommendations

I do not find any gaps in the structuring of the content, the accuracy and completeness of the description, as well as in the design of the presented documents for the dissertation work. The documents show a successful and productive research activity of Kristin Aleksandrova.

The doctoral student has the following two questions:

- Where and how is the processed data from the sensors and smart devices stored when the system is operating in real conditions and can it have wider use in future research?

- Is the created prototype accessible and how can access be obtained?

Systems of this type have the potential to increase the quality of life of the elderly and provide vital support in their daily activities. I recommend the PhD student to continue her work on the subject

and develop the current research. In order to acquaint a wider scientific community with the achieved results, it is good to present them in specialized publications with an impact factor.

7. Conclusion

Having become acquainted with the PhD thesis presented in the procedure and the accompanying scientific papers and on the basis of the analysis of their importance and the scientific and applied contributions contained therein, I **confirm** that the presented PhD thesis and the scientific publications to it, as well as the quality and originality of the results and achievements presented in them, meet the requirements of the ADAS in the Republic of Bulgaria, the Rules for its Implementation and the corresponding Rules at the Sofia University "St. Kliment Ohridski" (FMI-SU) for acquisition by the candidate of educational and scientific degree "Doctor" in the Scientific field 4. Natural Sciences, Mathematics, and Informatics, Professional field: 4.6. Informatics and Computer Sciences. In particular, the candidate meets the minimal national requirements in the professional field and no plagiarism has been detected in the scientific papers submitted for the procedure.

Based on the above, **I strongly recommend** the scientific jury to award **Kristin Ilieva Aleksandrova**, the educational and scientific degree "Doctor" in the Scientific field 4. Natural sciences, mathematics and informatics, Professional field 4.6. Informatics and computer sciences, Doctoral program "Information systems - Knowledge-based systems".

Date: 6.06.2024   Reviewer: ....
                                   / Prof. Daniela Orozova, DSc./

ADASRB - Act on Development of the Academic Staff in the Republic of Bulgaria