



VNiVERSIDAD
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IMPROVING PERSONALIZED ELDERLY CARE

AN APPROACH USING COGNITIVE AGENTS TO
BETTER ASSIST ELDERLY PEOPLE

DISSERTATION
submitted in partial fulfillment
of the requirements for the Doctor degree in
Informatics Engineering

by
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STATEMENT OF INTEGRITY

I, Diogo Emanuel Pereira Martinho, confirm that the work presented in this document is of my authorship. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

All the work described in this thesis was carried out in the Department of Informatics and Automation at the University of Salamanca, Spain, under the supervision of Juan Manuel Corchado Rodríguez and in the Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Porto, under the supervision of João Miguel Ribeiro Carneiro and Maria Goreti Carvalho Marreiros. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others except as specified in the text and summarised in the Statement of Contributions.

This dissertation is not substantially the same as any that I have submitted or is being concurrently submitted for a degree, diploma, or other qualification at the University of Salamanca or any other University or similar institution.

Porto, June, 2023,

Diogo Emanuel Pereira Martinho

To Ana and Bitó

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ABSTRACT

The aging of the population at a global level is an increasingly constant presence in daily life, and the consequences arising from this problem are becoming more and more impactful for the proper functioning and structuring of society. In this context, we speak of implications regarding economic growth, lifestyles (including retirement), family relationships, government resources available to the elderly, and, inevitably, the prevalence of chronic diseases. In the face of this reality, there arises a need for the development and promotion of effective strategies in the monitoring, prevention, and stimulation of active and healthy aging in the population. This ensures that elderly people continue to have a relevant role in society rather than being subjected to isolation and easy deterioration of their physical, cognitive, emotional, and social abilities. It makes sense to take advantage of all the technological developments that have occurred in recent years, particularly in mobile devices, artificial intelligence, and monitoring systems, to create solutions capable of providing daily support. Such solutions can collect health data and indicators and provide personalized actions that motivate adopting better health habits and means to achieve active and healthy aging. The challenge, therefore, is to encourage this population to merge their daily lives with the interest and willingness to use applications and systems that provide this personalized support. Some of the approaches recently explored in the literature with promising results to meet this goal are based on the use of gamification techniques and incentives to fulfill health challenges (as if the person were playing a game) and the use of personalized interactions with objects (whether physical, like robots, or virtual, like avatars) capable of providing more personal feedback, thus creating a closer connection between both the user and the system.

The work presented here combines these ideas and results in an intelligent approach to promoting the well-being of the elderly population through a personalized healthcare system. This system incorporates various gamification techniques to encourage better habits and behaviors. It uses a cognitive Virtual Assistant capable of understanding the user's needs and interests to provide personalized feedback and interaction to assist and motivate in fulfilling the identified challenges and objectives.

The proposed approach was validated through a study involving 12 elderly users, and significant results were achieved regarding usability, acceptance, and health effects. Specifically, the results support the importance and positive impact of combining gamification techniques and interaction with a cognitive Virtual Assistant that translates the user's health progress. Significant improvements in health outcomes were obtained after the intervention. Additionally, the usability results obtained through completing a usability questionnaire confirmed good adherence to the presented approach. These results thus validate the research hypothesis studied in the development of this dissertation.

Keywords: Elderly; Gamification; Cognitive Assistants; Personalized Healthcare

RESUMO

O envelhecimento da população a nível global é uma constante cada vez mais presente no quotidiano e as consequências derivadas deste problema são cada vez mais impactantes para o correto funcionamento e estruturação da sociedade. Neste contexto, falámos de consequências a nível de crescimento económico, estilos de vida (e aposentamento), relações familiares, recursos disponibilizados pelo governo à faixa etária mais idosa e inevitavelmente a prevalência de doenças crónicas. É perante esta realidade que surge a necessidade de desenvolvimento e promoção de estratégias eficazes no acompanhamento, prevenção e estímulo ao envelhecimento ativo e saudável da população de forma a garantir que as pessoas idosas continuem a ter um papel relevante na sociedade ao invés de se sujeitarem ao isolamento e fácil deterioramento das capacidades físicas, cognitivas, emocionais e sociais. Desta forma faz todo o sentido tirar partido de todos os desenvolvimentos tecnológicos verificados nos últimos anos, principalmente no que diz respeito a avanços nas áreas de dispositivos móveis, inteligência artificial e sistemas de monitorização e criar soluções capazes de dar apoio diariamente ao recolher dados e indicadores do estado de saúde e em resposta disponibilizar diversas ações personalizadas que motivem à adoção de melhores hábitos de saúde e meios para conseguirem atingir este envelhecimento ativo e saudável. O desafio passa então por conseguir motivar esta população a conciliar o seu dia-a-dia com o interesse e vontade em utilizar aplicações e sistemas que forneçam este apoio personalizado. Algumas das abordagens recentemente exploradas na literatura com este objetivo e que têm atingido resultados promissores baseiam-se na utilização de técnicas de gamificação e de incentivo ao cumprimento de desafios a nível de saúde (tal como se a pessoa tivesse a jogar um jogo) e a utilização de interações personalizadas com objetos (sejam eles físicos como robots ou virtuais como avatares) capazes de fornecer feedback mais pessoal criando assim uma ligação mais próxima entre ambas as entidades.

O trabalho aqui apresentado combina estas ideias e resulta numa abordagem inteligente para a promoção do bem-estar da população idosa através de um sistema de cuidados de saúde personalizado. Este sistema incorpora diversas técnicas de

gamificação para a promoção de melhores hábitos e comportamentos, e utilização de um assistente virtual cognitivo capaz de perceber as necessidades e interesses do utilizador de forma a possibilitar um feedback e interação personalizada no sentido de auxiliar e motivar ao cumprimento dos diferentes desafios e objetivos que sejam identificados.

A abordagem proposta foi validada recorrendo a um estudo com 12 utilizadores idosos e foram alcançados resultados significativos em termos de usabilidade, aceitação e efeitos de saúde. Mais especificamente, os resultados conseguidos permitem apoiar a importância e o efeito positivo da combinação de técnicas de gamificação e interação com um assistente virtual cognitivo que traduza o progresso do estado de saúde do utilizador, ao terem sido obtidas melhorias significativas nos resultados de saúde após a intervenção. Além disso, os resultados de usabilidade obtidos por meio do preenchimento de um questionário de usabilidade confirmaram a boa adesão à abordagem apresentada. Estes resultados permitem assim validar a hipótese de investigação estudada no desenvolvimento desta dissertação.

Palavras-chave: Idosos; Gamificação; Assistentes Cognitivos; Saúde Personalizada

RESUMEN

El envejecimiento de la población a nivel global es una constante cada vez más presente en el día a día y las consecuencias derivadas de este problema son cada vez más impactantes para el correcto funcionamiento y estructuración de la sociedad. En este contexto, hablamos de consecuencias a nivel de crecimiento económico, estilos de vida (y jubilación), relaciones familiares, recursos disponibles por el gobierno a la franja etaria más anciana e inevitablemente la prevalencia de enfermedades crónicas. Es ante esta realidad que surge la necesidad de desarrollo y promoción de estrategias eficaces en el acompañamiento, prevención y estímulo al envejecimiento activo y saludable de la población para garantizar que las personas ancianas continúen teniendo un papel relevante en la sociedad en lugar de someterse al aislamiento y fácil deterioro de las capacidades físicas, cognitivas, emocionales y sociales. De esta forma, tiene todo el sentido aprovechar todos los desarrollos tecnológicos verificados en los últimos años, principalmente en lo que se refiere a avances en las áreas de dispositivos móviles, inteligencia artificial y sistemas de monitoreo y crear soluciones capaces de brindar apoyo diariamente al recopilar datos e indicadores del estado de salud y, en respuesta, proporcionar diversas acciones personalizadas que motiven la adopción de mejores hábitos de salud y medios para lograr este envejecimiento activo y saludable. El desafío consiste en motivar a esta población a conciliar su día a día con el interés y la voluntad de utilizar aplicaciones y sistemas que brinden este apoyo personalizado. Algunas de las abordajes recientemente explorados en la literatura con este objetivo y que han alcanzado resultados prometedores se basan en la utilización de técnicas de gamificación e incentivo al cumplimiento de desafíos a nivel de salud (como si la persona estuviera jugando un juego) y la utilización de interacciones personalizadas con objetos (ya sean físicos como robots o virtuales como avatares) capaces de brindar feedback más personal, creando así una conexión más cercana entre ambas entidades.

El trabajo aquí presentado combina estas ideas y resulta en un enfoque inteligente para la promoción del bienestar de la población anciana a través de un sistema de cuidados de salud personalizado. Este sistema incorpora diversas técnicas de gamificación para la promoción de mejores hábitos y comportamientos, y la utilización

de un asistente virtual cognitivo capaz de entender las necesidades e intereses del usuario para posibilitar un feedback e interacción personalizados con el fin de ayudar y motivar al cumplimiento de los diferentes desafíos y objetivos que se identifiquen.

El enfoque propuesto fue validado a través de un estudio con 12 usuarios ancianos y se lograron resultados significativos en términos de usabilidad, aceptación y efectos de salud. Específicamente, los resultados obtenidos permiten respaldar la importancia y el efecto positivo de combinar técnicas de gamificación e interacción con un asistente virtual cognitivo que traduzca el progreso del estado de salud del usuario, ya que se lograron mejoras significativas en los resultados de salud después de la intervención. Además, los resultados de usabilidad obtenidos mediante la cumplimentación de un cuestionario de usabilidad confirmaron la buena adhesión a el enfoque presentado. Estos resultados validan la hipótesis de la investigación estudiada en el desarrollo de esta disertación.

Palabras-clave: Ancianos; Gamificación; Asistentes Cognitivos; Atención Médica Personalizada

STATEMENT OF CONTRIBUTIONS

Due to this project's collaborative and interdisciplinary nature, some of the work and results presented in this thesis could only be achieved with the help of brilliant people, to whom I am very grateful. These people are: **Dr. Alberto Freitas**, and his lab members at the Center for Health Technology and Services Research, in the Faculty of Medicine of Porto, Portugal, for providing insight and knowledge in developing machine learning techniques explored throughout the development of the Ph.D. Work; **Dr. Kenji Matsui** and their lab members at Osaka Institute of Technology, Japan, for providing knowledge and teaching on how the validation study presented in this Ph.D. work should be performed. All experiments in this thesis were conceived and designed by my Ph.D. supervisors, **Dr. Juan Corchado**, **Dr. João Carneiro**, **Dr. Goreti Marreiros**, and me. Additional input was given from other researchers at the Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development (GECAD), Portugal, for the particular experiments they contributed to.

CONTENTS

1 Introduction	1
1.1 Motivation	1
1.2 Objectives	5
1.3 Outline and Major Contributions	8
1.4 Document Structure.....	13
2 Contributions	15
3 Conclusions and Future Work	21
3.1 Main Conclusions and Contributions.....	21
3.2 Future Work.....	23
3.3 Dissemination of Results and Relevant Work	24
3.3.1 Other Publications.....	24
3.3.2 Participation and Organization of Events	26
3.3.3 Invited Presentations.....	27
3.3.4 Lecturing.....	28
3.3.5 Supervision of Students	29
References	31
Appendix A. Core Publications	41
A Conceptual Approach to Enhance the Well-Being of Elderly People ...	41
Defining an Architecture for a Coaching Module to Support Self- Monitoring of Chronic Obstructive Respiratory Diseases	43
A Multiple Criteria Decision Analysis Framework for Dispersed Group Decision-Making Contexts.....	45
A Definition of a Coaching Plan to Guide Patients with Chronic Obstructive Respiratory Diseases	47
A Systematic Review of Gamification Techniques Applied to Elderly Care.....	49

A Hybrid Model to Classify Patients with Chronic Obstructive Respiratory Diseases.....	53
A Reinforcement Learning Approach to Improve User Achievement of Health-Related Goals	55
An Intelligent Coaching Prototype for Elderly Care.....	57
Appendix B. Preprint	59
Effects of a Gamified Agent-Based System for Personalized Elderly Care: A Pilot Usability Study.....	59
Appendix C. Conclusions in Spanish	63
Conclusiones Principales, Contribuciones y Trabajo Futuro	63

ILLUSTRATIONS

Figure 1 - CoaFEld System Architecture.	11
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TABLES

Table 1 - Ph.D. thesis main contributions, related objectives, and publications.15

ABBREVIATIONS

AAL: Ambient Assisted Living

AI: Artificial Intelligence

AIRDOC: Aplicação móvel Inteligente para suporte individualizado e monitorização da função e sons Respiratórios de Doentes Obstrutivos Crónicos/ Smart Mobile Application for Individualized Support and Monitoring of the Respiratory Function and Sounds of Chronic Obstructive Patients

API: Application Programming Interface

COAFELD: Coaching for Elderly

CORD: Chronic Obstructive Respiratory Disease

GECAD: Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development

JCR: Journal Citation Report

MAS: Multi-Agent System

ML: Machine Learning

PHE: Personal Health Empowerment

R&D: Research and Development

RL: Reinforcement Learning

SCI: Scientific Citation Index

1 INTRODUCTION

“Somewhere, something incredible is waiting to be known.”

– Sharon Begley

This chapter presents an outline of the overall aspects of the development of this thesis. In this sense, contextualization of the topics under which this work was developed is first presented with a clear indication of the existing limitations and challenges that fall into the scope of the thesis and are the base of the proposed solution. The hypothesis studied in this work is then identified, and objectives are established to answer it. Finally, the structure of this document is presented. As this thesis is organized according to a format called "Compilation Based" or "Scandinavian model", a summary of each of the publications inserted in this document is also presented in this chapter.

1.1 MOTIVATION

Lifespan is increasing worldwide. Almost anyone is expected to live until the age of sixties and beyond. In fact, according to the World Health Organization's latest reports on Ageing and Health, we know that by 2030 1.4 billion people will be over 60 years old, increasing to at least 2.1 billion before 2050 [10]. With such a significant growth in the number of elderly people living in our world, the public concern on how to allow this age group of people to stay active and relevant in society arises as an

attempt to avoid the social isolation phenomenon. Science, medicine, and psychology tell us that social isolation has a devastating effect on mental and physical health [11, 12] and contributes to decreasing the quality of life and the aging process of elderly people. As a result, several adverse psychological conditions are aggravated, such as anxiety, depression, and suicidal tendency, [13, 14], not to mention all the known physical and mental effects with the increase of chronic conditions like diabetes, obesity, heart disease, dementias, arthritis, among others. All these factors are the leading cause of death, illness, long-term disability, and high healthcare costs required to assist elderly people [15]. In this context, authors have been growing interested in researching and developing assistive solutions to help elderly people [16, 17] combined with ambient intelligence technologies [18, 19]. Among many of the already available technologies, it is highlighted the use of telecare devices [20-22], persuasive technologies [23, 24], rehabilitation systems [25, 26], and digital games [27-31] with the supportive goal in mind. While many of these technologies have already been explored over the last decade with many successful results [32-38], the use of games and game design elements in nongame settings is quite novel [39-47] and even more when considering such approach in a healthcare context to support elderly people [48-53]. Nowadays, we associate this new use of games in more serious contexts to two main concepts described as serious games and gamification.

Serious games are often regarded as games “designed to entertain players as they educate, train, or change behavior” [54]. A common approach for developing serious games is using exergames or video games that encourage exercise for groups of individuals that may be reluctant to engage in the more traditional forms of exercise [55]. Several studies have compared the effectiveness of video game-based approaches to conventional exercise methods [56] and obtained far more positive results regarding the acceptability, usability, and enjoyment of one approach than the latter. Regarding the health conditions addressed, many studies focus on mobility and physical-related conditions compared to neurological or mental-related disorders. Only a few studies consider both types of interventions [57].

Regarding technological trends, there is a solid preference for developing exergames using console platforms such as Microsoft Kinect, Nintendo Wii, or Nintendo Switch, which are targeted for home-based exercise programs. Authors refer to the main advantages of this kind of platforms which includes controlling movement through full body tracking capabilities [57-62], affordability [63, 64], or more accessible interactions without the use of remote controllers [65]. Besides this, some of the proposed works also consider the use of peripherals, such as ergometers and pressure mat sensors which can provide some benefits in terms of costs and allow simple movements and minimal configurations [57]. Finally, regarding the health response of all these kinds of interventions, authors have reported very positive results regarding improved balance and muscle strength, which can reduce the risk of falls [60, 61, 63, 65-69]. Balance and gait were also compared with cognitive function. Some authors found a significant relation between the former two with the latter and identified that adverse outcomes in cognitive capabilities would frequently lead to decreased balance and gait function [70-75]. Authors have reported significant improvements in cognitive performance, physical condition, and other advantages such as reduced intergroup anxiety and reception towards exergames and more entertaining and engaging play sessions [56].

Gamification refers to the enhancement of services with features that can offer “gameful” experiences to its users and keep users motivated and engaged, increasing their activity, social interaction, and the quality and productivity of their actions [76]. Companies are now extending (and ‘gamifying’) their existing services, and more investments are being made toward developing gamified applications and serious games [76]. Likewise, recent research and advancements in gamification and serious games have been made in healthcare [77-80]. There is a great focus on different health domains, such as promoting both physical and cognitive activity [81-85], promoting behavioral changes [77, 86], and providing personalized healthcare services for all ages [28]. These services can bring innovative and cost-effective solutions and treatments to the most fragile and isolated groups in our society, which correspond to elderly people and/or those suffering from chronic diseases [84, 87].

Furthermore, personalization becomes an essential aspect of this kind of service as individual necessities and capabilities are even more impactful to this age group. The lack of personalized mechanisms could lead to a quick disinterest in using the healthcare service. In the context of elderly care, this could easily result in the deterioration of health conditions. In this context, the potential of gamification and the use of serious games is now being studied as a way to deliver more effective and personalized services to elderly people and to encourage and persuade them to undertake both physical, cognitive, and social or/group activities according to their capabilities and needs, thus contributing to their overall wellbeing and to pursue more active and healthy lifestyles [28, 88, 89]. Regarding the target audience in elderly care, several works have been designed for both home environment and individual use and for communities to be used by several elderly people simultaneously [5].

Additionally, many works were found to be more focused on physical rehabilitation and stimulation when compared to mental and cognitive rehabilitation [5]. In terms of game design elements, it was observed that many existing works highlight the importance of including feedback and motivational mechanisms to persuade the user to follow through with health-related activities [5]. The authors stress the importance of providing adequate, timely support for effective interventions, especially in elderly care. In this sense, different strategies have been explored using many technological features ranging from the everyday use of mobile and/or wearable devices (such as smartphones, smartbands or smartwatches) to retrieve and measure user activity data and in provide feedback and recommendations accordingly, to the use of more social and interactive approaches (such as robots and Virtual Assistants) to offer a closer and more personal experience with the user [5].

The interest in developing Virtual Assistants to support elderly people has increased significantly over the recent years, given all the technological advancements in terms of computational tools [90, 91], voice assistant technologies [92, 93], and conversational machine learning (ML) mechanisms [94-98]. Authors have clearly described the benefits of allowing more social and emotional interactions [99, 100] with the elderly person and between groups [101] and improving their capabilities

while not replacing them in specific tasks. Several advantages arise from using Virtual Assistants in the context of elderly care. First, these assistants can establish a social bond and manage the loneliness of elderly people with features that range from speech and text recognition to interactive learning mechanisms to establish personalized conversations and/or other social actions (such as playing games, music, or even reading out latest news) with the user [91]. Second, these assistants can serve as the bridge between the elderly person and his/her family members, friends, and the community by providing different features such as direct messaging or calls [91]. Finally, Virtual Assistants can decrease the impact of negative feelings such as loneliness, boredom, depression, frustration, and so on through active listening skills, cognitive behavioral therapy, personalized coaching sessions, and persuasive strategies to improve the user's well-being [91]. Some authors have also referred to the importance of intelligent cognitive assistants to support attitude and behavior changes, which are crucial to protect against the deterioration of cognitive and mental health [102]. Furthermore, other authors explain the importance of building a relationship with a virtual entity and why this approach could be meaningful for the elderly person, promoting feelings of responsibility and even nostalgia as they look after another person/being [103-105].

1.2 OBJECTIVES

The development of intelligent mechanisms and algorithms to adjust the interaction and support provided to the elderly person, which includes serious games with a scalable difficulty till robots that play games and communicate with elderly people using different emotions, is fundamental to ensure interactive and personalized systems that are tailored to each user and more importantly to the elderly person [5]. In this regard, the study of effective feedback and reward strategies is fundamental to allow more intelligent interactions and increase the cognitive/physical load as the user becomes more proficient with the system and to consider methods that enhance and promote social interaction, which can result in more personalized elderly care solutions. Furthermore, adapting the support provided to the elderly person according

to their interests, capabilities, and necessities, and the surrounding environment will contribute to the improvement of health and wellbeing, capture interest and ensure positive engagement, facilitate social interaction, and decrease the impact of many different medical conditions which in short and long-term may bring impactful consequences in the overall quality of life of the elderly person.

With these ideas highlighted, the work proposed here focuses on the definition and development of an approach to promote the wellbeing of elderly people using a cognitive agent (and the derived cognitive mechanisms) to understand the needs and capabilities of each elderly person and adapt the interaction and support provided accordingly. Besides that, it will also be studied how support can be delivered to stakeholders and how their knowledge can be used to assist the elderly person better. The research hypothesis that will be studied will be the following:

A Cognitive Agent that can process data related to the elderly person, such as health condition and behavior, can adapt the interaction and support provided better to satisfy the interests and necessities of the elderly person.

It is now proposed a list of objectives that should be accomplished throughout the development of the Doctoral work:

1. **Survey of the current state of the art** regarding:
 - a. Study gamification in Elderly Care, Ambient Assisted Living (AAL), and Smart Homes;
 - b. Analyze different bigdata driven architectures and platforms, main opportunities, and challenges in the three areas mentioned above.
2. **Analyze existent big data analytics for elderly care and human behavior**, including:

- a. The study of which machine learning algorithms can be used to identify human behavior;
 - b. Understand how user data processed by these algorithms can be used to improve the user's well-being (elderly person).
3. **Define how the data regarding the physical space and the user will be collected, processed, and stored**, including the definition of intelligent machine learning algorithms and mechanisms that can adapt the information and the interaction according to the necessities and capabilities of each user.
4. **Develop a Personalized Healthcare Service to operate inside and outside the considered environment:**
 - a. Operate inside the environment, collect and process data and interact with the environment and the user via installed sensors and intelligent devices;
 - b. Operate outside the environment, collect and process data and interact with the user through wearable devices and embedded sensors.
5. **Develop a Cognitive Agent**, which will interact with the user and provide suggestions of possible activities that can be performed which have been identified automatically using machine learning algorithms or provide instructions specified by the healthcare professional.
6. **Interact with stakeholders and provide feedback regarding user health data and performance.** With this information, the healthcare professional may provide instructions on possible activities, health goals, or personalized recommendations for the user.

7. **Test and validate the system using real and simulated data in a laboratory (by running simulations and developing a prototype) and in a real environment (by developing a pilot).**

The following chapter will present a list of published works addressing each of these objectives, explaining each significant contribution and how the objectives have been achieved.

1.3 OUTLINE AND MAJOR CONTRIBUTIONS

The accomplishment of all the objectives established for the development of this thesis and, consequently, the fulfillment of the answers to the research question identified has been done following the objectives and results reported throughout the development of the national R&D project NORTE-01-0247-FEDER-033275 (AIRDOC “Aplicação móvel Inteligente para suporte individualizado e monitorização da função e sons Respiratórios de Doentes Obstrutivos Crónicos”) by NORTE 2020 (Programa Operacional Regional do Norte)¹, and the international project EUREKA ITEA3 Project Personal Health Empowerment (PHE-16040)² with the participation and coordination of GECAD in several activities part of both projects. The execution of these projects assumed as the main objective the development of an intelligent and personalized solution to monitor and improve health conditions using personal data and technology-assisted coaching of patients with Chronic Obstructive Respiratory Diseases (CORD), such as asthma and rhinitis on sinusitis. To achieve this goal, innovative and intelligent measurements were applied in conjunction with the specification and development of monitoring tools for preventive healthcare, which could contribute towards cost-saving, self, and home-care solutions with increased patient involvement. Additionally, the solution completed throughout the development of this project assumed as a mandatory requirement the exclusive use of the smartphone and its embedded sensors to acquire all the necessary data to provide

¹ https://sigarra.up.pt/fmup/pt/projectos_geral.ficha_projecto?p_id=73608

² <https://itea4.org/project/personal-health-empowerment.html>

personalized support to the CORd patient. Some of the main outcomes obtained with the development of these projects, following the goals established for this thesis, included the specification of different business and user data models, as well as the definition of both reasoning, coaching, and rule-based systems and corresponding recommendations and/or health goals based on all the user data collected using the smartphone and mobile app developed.

In terms of dissemination, the main outcomes drawn from the development of this thesis originated several high-quality and high-impact scientific contributions in different areas of relevance related to the context of this work, including both Artificial Intelligence (AI), Medical Informatics, and Healthcare. This work comprises a total of five major publications in first and second-quartile JCR-indexed journals and four publications and participations in top-level conferences in Multi-Agent Systems, Healthcare, Artificial Intelligence, and Information Systems and Technologies. The nine publications are presented in Appendix A. Core Publications and Appendix B. Preprint, and their fundamental contributions to cover this Ph.D. thesis' objectives are presented in the following chapter addressing the main contributions towards fulfilling the objectives established for this thesis. The nine core publications are the following:

1. Martinho, D., Carneiro, J., Novais, P., Neves, J., Corchado, J., & Marreiros, G. (2019, September). A conceptual approach to enhance the well-being of elderly people. In *EPIA Conference on Artificial Intelligence* (pp. 50-61). Springer, Cham [1].
2. Vieira, A., Martinho, D., Martins, C., de Almeida, A., & Marreiros, G. (2019, July). Defining an Architecture for a Coaching Module to Support Self-Monitoring of Chronic Obstructive Respiratory Diseases. In *ICIMTH* (pp. 130-133) [2].
3. J. Carneiro, D. Martinho, P. Alves, L. Conceição, G. Marreiros, and P. Novais, "A multiple criteria decision analysis framework for dispersed

- group decision-making contexts," *Applied Sciences*, vol. 10, no. 13, p. 4614, 2020. [3].
4. Martinho, D., Vieira, A., Carneiro, J., Martins, C., Almeida, A., & Marreiros, G. (2020, April). A definition of a coaching plan to guide patients with chronic obstructive respiratory diseases. In *World Conference on Information Systems and Technologies* (pp. 54-64). Springer, Cham [4].
 5. Martinho, D., Carneiro, J., Corchado, J. M., & Marreiros, G. (2020). A systematic review of gamification techniques applied to elderly care. *Artificial Intelligence Review*, 53(7), 4863-4901 [5].
 6. Martinho, D., Freitas, A., Sá-Sousa, A., Vieira, A., Meira, J., Martins, C., & Marreiros, G. (2021). A Hybrid Model to Classify Patients with Chronic Obstructive Respiratory Diseases. *Journal of Medical Systems*, 45(3), 1-11 [6].
 7. Martinho, D., Carneiro, J., Neves, J., Novais, P., Corchado, J., & Marreiros, G. (2021, September). A Reinforcement Learning Approach to Improve User Achievement of Health-Related Goals. In *EPIA Conference on Artificial Intelligence* (pp. 266-277). Springer, Cham [7].
 8. Martinho, D., Crista, V., Carneiro, J., Corchado, J. M., & Marreiros, G. (2022). An Intelligent Coaching Prototype for Elderly Care. *Electronics*, 11(3), 460 [8].
 9. Martinho, D., Crista, V., Carneiro, J., Matsui, K., Corchado, J. M., & Marreiros, G. (Submitted, 2023). Effects of a Gamified Agent-Based System for Personalized Elderly Care: A Pilot Usability Study. *Journal of Medical Internet Research Serious Games* [9].

The combined contributions provided by the work developed in the scope of this thesis resulted in the design and development of the coaching solution named Coaching for Elderly (CoaFEld in short), specifically designed to support elderly people during their daily lives and which was initially conceptualized in [1] and finally proposed as a whole in [8]. CoaFEld was developed following a microservice-oriented architecture (Figure 1), composed of three main components: a user web application, an API gateway, and a set of microservices. These microservices communicate and store specific user information regarding user progress while using the application (using different gamification components), health status (derived from the performance of established coaching plans), and user interactions with the feedback that is provided to the user (personalized message interactions based on the user preferences). This information is then consumed and sent to the web application.

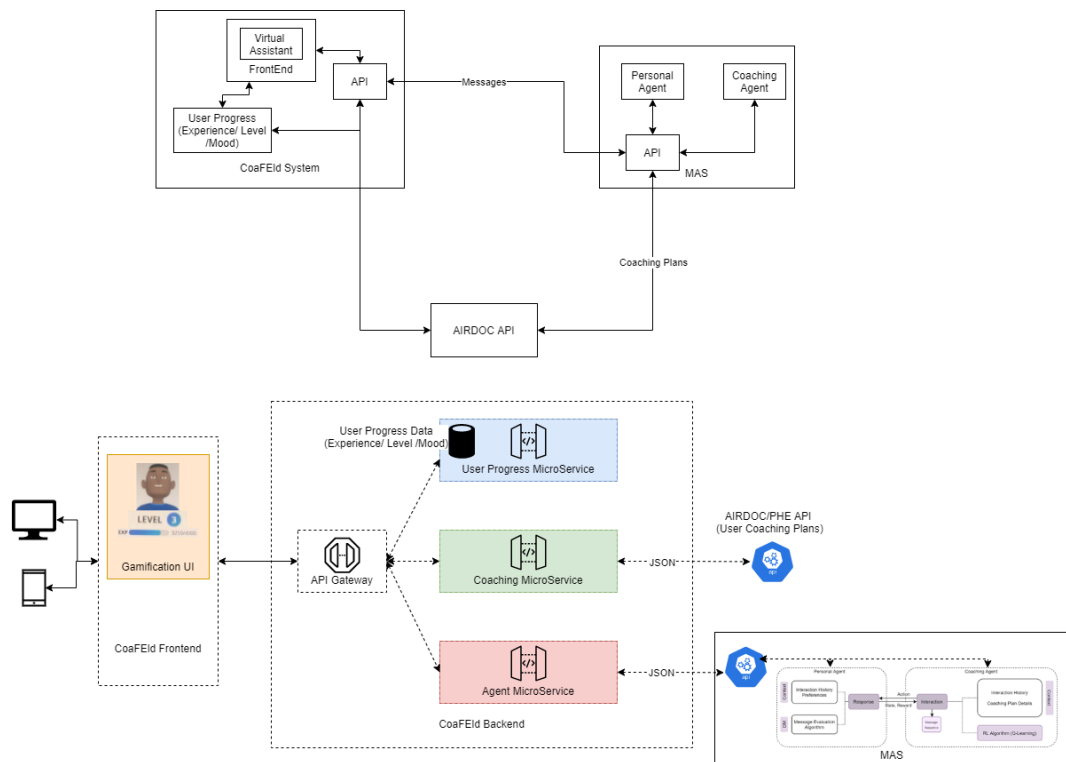


Figure 1 - CoaFEld System Architecture.

Additionally, an API Gateway was developed in the proposed work with the main goal of encapsulating a set of several microservices and providing an API that is

specific to each client (thus serving as a single-entry point into the system). It is also the responsibility of the API Gateway to include authorization/authentication functionalities and assure asynchronous communication between the requests sent to the available microservices. Three microservices were developed to store and provide information about user progress and health outputs.

- **User Progress Microservice**—This microservice was developed to manage the data related to user progress and actions within the coaching application. This includes all the information on current game experience/level/points; content unlocked; in-game purchases; cognitive play session results (games played, points and experience acquired, etc.); and Virtual Assistant configurations/emotional state.
- **Coaching Microservice**—This microservice was developed to configure and evaluate coaching plans with health-related goals. These goals follow a particular health topic (for example, physical activity or smoking habits) and measure an input variable the user provides as lower than/higher than/equal to a particular value or range. Another critical aspect of these goals is that they can be dynamically updated with increasing/decreasing difficulty, depending on the user's performance. Whether they complete (or not) similar goals that are established for a particular coaching plan (following the example of smoking habits, a daily goal of smoking fewer than a certain number of cigarettes per day could be updated for the following days depending on whether the person achieved this goal or not) Additionally, this microservice provides information on user performance for each associated coaching plan (number of goals already achieved, number of goals failed, upcoming goals, goals' difficulty, etc.).
- **Agent Microservice**—This microservice comprises a Multi-Agent System developed in Jade with the definition of two main agents that communicate with each other: A Personal Agent that returns the interaction (message queue), to be sent directly to the user, and evaluates the feedback provided by the user

in terms whether the user achieved a health goal after performing a certain interaction with him/her; A Coaching Agent that applies a Reinforcement Learning (RL) strategy (using a Q-Learning algorithm) to understand which interactions should next be sent to the user at specific moments of the day based on the information exchanged with the Personal Agent and the interactions with the user. This Reinforcement Learning strategy allows the system to learn from the older person as they provide more feedback and understands which messages are most influential in motivating the person to achieve their health goals. Then, future interactions can be adapted according to this information.

1.4 DOCUMENT STRUCTURE

This document is composed of three chapters. This first chapter explains the motivation for developing this thesis, an overview of the most relevant topics related to this work, the research question and respective objectives established, and the outline and a summary of the main contributions provided throughout the development of this thesis.

The second chapter details the most relevant contributions composing the doctoral thesis and discusses how each presented publication addresses the research question and the different objectives established.

Finally, the third chapter identifies the main conclusions and findings obtained with the development of this thesis. A discussion regarding the future work to be explored in a sequence of the results achieved with this thesis is also presented. Additionally, this chapter is also presented in Spanish in the Appendix C. Conclusions in Spanish.

2 CONTRIBUTIONS

“No matter what people tell you, words and ideas can change the world.”

– Robin Williams

In this chapter, all main contributions are presented, comprising a total of nine publications that cover all the essential parts of the work and results achieved during the development of this thesis. Each of these publications answers the different objectives established for the development of this thesis as follows:

Table 1 - Ph.D. thesis main contributions, related objectives, and publications.

CONTRIBUTION	RELATED OBJECTIVE	PUBLICATION								PREPRINT	
		1	2	3	4	5	6	7	8		9
Comprehensive overview of state of the art on elderly care, gamification techniques, ambient assisted living, and smart homes	1	X				X					
User health data analytics	2 & 3			X			X				
Multi-agent system for the coaching of the elderly	4, 5, 6 & 7							X	X		
Personalized elderly care service	4, 5, 6 & 7	X	X	X	X	X		X	X		
Machine learning models & artificial intelligence techniques for user health and behavioral data	2 & 3	X	X		X	X	X	X	X		
Experimentation and validation	8							X	X	X	

In terms of main contributions, the first contribution achieved during the development of this thesis was to perform a complete study of the current state of the

art regarding all the fundamental topics related to the context of elderly care, including the study of gamification techniques, ambient assisted living, and smart home technologies. Two of the works published contributed to this contribution [1, 5], in which several of the latest works proposed in the literature were studied in terms of techniques, models, discussions, and results achieved in this context. Although a considerable amount of work is already proposed in the literature on gamification techniques applied to elderly care, comprehensive reviews of the most recent work done in this context were still very lacking. Therefore, regarding this contribution, a systematic review of the advancements in gamification and associated techniques applied to elderly care was performed [5]. For that, six different research questions were studied and discussed throughout this work to describe the current state of the art on the existing personalized elderly care services and their correlation with gamification technologies so that it can then be possible to establish a background for researchers to pursue their research activities in this area. The selected studies were revised regarding publication source types, research areas and target audience. Then, each selected work was analyzed in more detail to understand what kind of game design elements and technological features were employed by authors in their proposals. Finally, the perceived challenges to overcome and the benefits were explored to understand how gamification techniques can be successfully integrated into personalized elderly care solutions. In the second study [1], some of the most recent approaches under cognitive assistants and affective wearables applied to healthcare focused on elderly care were explored. These artificial intelligence techniques are closely related to ambient assisted living and smart homes and are essential to define a personalized elderly care solution. As a result, of this study, a conceptual formalization of an architecture to build a personalized healthcare solution for the elderly was also proposed, which served as the basis for developing the healthcare solution presented in this thesis.

The second contribution achieved was related to the analysis of user health data. For this case, a publication was published with a clustering study with user health data acquired within the context of the PHE and Airdoc project [6]. In this work, analysis and clustering of patients with chronic obstructive respiratory diseases were performed

using a hybrid modeling approach to identify different groups of users. A classification model with 90.4% prediction accuracy was generated by combining agglomerative hierarchical clustering and decision tree classification techniques. Furthermore, this model identified 5 clusters that describe the characteristics of 5 types of users according to 7 generated rules. With the modeling approach defined in this study, a personalized coaching solution was built considering patients with different necessities and capabilities and adapted the support provided, enabling the recognition of early signs of exacerbations and accurate self-monitoring and treatment of the disease. The novel factor of this approach resided in the possibility of integrating personalized coaching technologies adapted to each kind of user within a smartphone-based application resulting in a reliable and affordable alternative for patients to manage their disease.

The third contribution was related to the development of a MAS to represent and support different stakeholders and had as the main contribution the publication made in [7], in which the architecture and agents of the MAS were introduced. This system includes both agents that support the patient and follow their preferences and needs and a coaching agent who represents the healthcare professional and persuades other agents to accomplish health-related goals by using a Reinforcement Learning strategy to identify the best sequence of messages to exchange with those agents (based on their preferences and needs). To validate our proposed model, we selected different simulation scenarios, which include various types of messages that can be exchanged with the user (by the personal agent). We observed how easily the coaching agent could identify the best sequence of action compared to a “normal” coaching agent that did not use this approach and attempted to persuade other agents with random sequences of messages. We were able to observe significant advantages over the use of RL for this purpose. We also identified other benefits of our proposal related to the generic structure applied in the RL process.

The fourth contribution was the development of a personalized healthcare solution for the elderly, which had as the main contributions the publications made in [3] and [8]. In the first publication a Multiple Criteria Decision Analysis Framework

was proposed with the development of a microservice, used by autonomous software agents to support decision-makers according to their specific needs/interests and suggest recommendations on different daily life activities such as healthy choices for dining and places to practice physical activity. This framework allowed to enhance the support provided to decision-makers so they can attain more informed, consistent, and satisfactory decisions. In the second work, we presented the CoaFEld coaching system specifically designed to support elderly people during their daily lives and motivate them to pursue healthier ways of living, which will, in turn, contribute to an active and healthier aging process. As such, we combined different ideas introduced in [1, 2, 4, 5, 7], along with a gamified approach. By doing this, we enhanced the support given to the elderly person according to his/her evolution as a player and user of the coaching system by providing him/her with different types of feedback and motivational features depending on his/her performance and progress. Our approach considered a cognitive assistant that interacts with the elderly person and reacts based on the performance of the elderly person as a player of the system. To do this, the cognitive assistant displays different emotional states to represent the person's health progress, which improves as the user improves their health condition. Furthermore, the proposed system offered additional gamification elements and strategies generally well-perceived by the elderly population and will contribute to an overall enhanced user experience.

The fifth contribution was completed in parallel with the results achieved throughout the development of this thesis. First, with the initial overview of state-of-the-art [1, 5], a study was made regarding existing ML models and AI techniques applied in the latest proposals in the literature. With the clustering analysis performed in [6], the ML model was obtained using hierarchical clustering to identify different groups of users based on their health data. With the development of the coaching component in [2, 4], a rule-based system was developed to process user data and provide different health-related outcomes and feedback based on medical and scientific guidelines, including reasoning algorithms such as case-based reasoning explained in [106]. With the work published in [7], the MAS also combined an RL technique to learn user interests and preferences over time. Finally, the healthcare

solution completed in [8] combined several gamification elements to draw the user's interest and motivate him to use the system and improve health-related habits. A cognitive agent was designed and endowed with emotional mechanisms to interact with the elderly person and provide feedback on their progress while using the application and following established coaching metrics such as recommendations or goals.

The last contribution is related to the experimentation and validation of the proposed system. In terms of the experiment, in both works proposed in [7, 8], different simulations were conducted to validate the reinforcement learning and the cognitive assistant emotional progress approaches applied in this Ph.D. work. Regarding the validation of the system, a final validation study was performed in [9] with the main goal of investigating the feasibility and usability of the developed gamified agent-based system and obtaining initial results on the effectiveness of the intervention regarding physical activity health outcomes. This study was designed as an intervention study with the participation of 12 elderly people over seven days (1 week), and step count data was collected with access to Google Fit API. The results regarding step count data were compared before and after the intervention for each participant through average step count data before the intervention (average daily values over four weeks before the intervention) and the daily step count data during the week of the intervention. Student t-test was used to determine the relation between the dependent and independent variables. The post-test results were significantly high regarding pre- and posttest changes ($P=.017$; Student t-test at 95% confidence level), with a moderate effect size (Cohen's D of 0.77).

Regarding usability, participants were asked to answer the System Usability Scale questionnaire, and the developed application obtained an average usability score of 78 (out of 100). With the obtained results, the presented pilot was validated showing the positive health effects on the use of gamification techniques and a virtual cognitive assistant. Additionally, usability metrics considered for this study confirmed the high adherence and interest from most participants to the pilot.

Appendix A. and Appendix B. present each publication according to the order presented in Table 1. All publications are preceded by a table that presents all the relevant information regarding the work and the publication source. Lastly, a summary in Spanish of each publication is also provided.

3 CONCLUSIONS AND FUTURE WORK

“When everything gets answered, it’s fake.”

– Sean Penn

In this chapter of the manuscript, the most relevant conclusions derived from the results achieved during the development of this work are presented while also giving directions for possible future work in the continuation of the current research.

3.1 MAIN CONCLUSIONS AND CONTRIBUTIONS

With the increase in the percentage of elderly people living today, new intelligent approaches and strategies are being explored to allow this group of more frail individuals to remain active and face a less impactful decrease in their health condition and well-being while growing older. In this context, developing personalized healthcare systems capable of supporting older people in their daily lives becomes necessary to take advantage of the latest technological advances combined with successful engagement strategies to persuade and motivate elderly people towards positive behavior changes. Among all the different ideas and existing proposals, many studies highlight the potential to consider more interactive mechanisms to draw user attention with successful results regarding using gamified systems in healthcare and, more specifically, in elderly care. These systems, empowered with game-like features, can offer more engaging and entertaining experiences to captivate user interest using features to contribute to physical, cognitive, emotional, and even social positive stimulation, which in turn answers the healthy aging concern. These points greatly

inspired the thesis work presented in this manuscript. Significant research was undertaken to understand how a gamified healthcare system designed with particular gamification techniques and persuasive and behavioral strategies could improve the health and well-being of the elderly person. As such, the derived central research hypothesis here studied aimed to answer whether using a cognitive agent that processes data related to the elderly person, such as health condition and behavior, can better adapt the interaction and support provided to satisfy the interests and necessities of the elderly person. For this, a gamified coaching application was developed (named as CoaFEld) with different elements to motivate the user and enhance user experience, which considers a cognitive assistant to interact directly with the elderly person and provide them with feedback related to the progress of the health condition. Different emotional queues to represent the user's progress are given, which can be increasingly more positive as the user's health condition improves or increasingly more negative as the user's health condition decreases.

The achieved results show that it was possible to validate the impact of the Virtual Assistant and the overall gamified solution developed within the CoaFEld application with the participation of different users aged 55 years or older and obtained significant results in terms of usability, acceptability, and effectiveness of the considered approach. The validation study highlighted the importance and positive effect of combining gamified elements and a social engagement strategy with a Virtual Assistant to translate user progress in a healthcare setting. The obtained results favored the use of the CoaFEld app with improved health outcomes after the intervention when compared to the health data obtained before the intervention ($P=.017$ calculated with Student t test when $P<.05$), with a Cohen's D effect size of 0.77 which is moderate yet close to large size (effect size >0.8). Additionally, usability results obtained through the completion of the SUS questionnaire also confirmed high acceptability and usability, with an average usability score of 78 received, along with overall positive comments from the participants expressing their intentions to keep using the application after the intervention period was completed.

The findings resulting from the development and validation of CoaFeld, with the achievement of the objectives established to answer the presented research hypothesis, have contributed to significant outcomes in state of the art in artificial intelligence and healthcare. The main contributions to the artificial intelligence area were principally given in the fields of machine learning and multi-agent systems, while in the context of healthcare were explicitly related to elderly care and enhancement of well-being and health condition through both cognitive, physical, emotional, and social stimulation. Nine main scientific papers were published as a result of this Ph.D. work, and the contribution of this work towards the achievement of the AIRDOC project and related objectives are strong indicators of the importance of the achieved findings.

3.2 FUTURE WORK

In future work, we intend to improve the proposed coaching system to consider higher-complexity scenarios and people with more complex behaviors and ways of living. Additionally, we want to incorporate our approach with devices that can provide real-time data and monitor the patient's health condition directly, such as smartbands to measure the accuracy and impact of each interaction performed between the proposed system and the elderly person. We also intend to improve our gamified system by (1) including additional users (family) that can provide additional content and rewards to the elderly person; (2) establishing cognitive plans that can be explicitly evaluated based on cognitive outcomes drawn from the use of the application.

Another point of improvement is reaching more results and conclusions regarding usability and acceptability, as explained in [9]. It is necessary to study the effectiveness of the proposed work together with elderly people with advanced age and to measure the long-term performance compared to the short-term performance and results already obtained for one week.

Finally, it would also be interesting to explore more direct strategies for more critical environments, especially when dealing with very frail and old individuals (in which the use of a complex technological tool might just be too overbearing) with the

help of on-site robots that can incorporate the technologies here developed to assist and interact with the elderly person guiding towards the achievement of successful health outcomes.

With these points in mind, it will be possible to increasingly improve the intelligent approach here presented with better tools to support the elderly person during their daily life and promote and motivate active and healthy aging.

3.3 DISSEMINATION OF RESULTS AND RELEVANT WORK

Several relevant outcomes were disseminated and achieved, resulting from many ideas explored and of the research work undertaken throughout the development of the Ph.D. Combined, these results tell the story and the paths which allowed me to learn, experience, and face new opportunities and challenges critical to acquiring and improving skills both as a researcher and a person.

3.3.1 Other Publications

Alongside all the main publications necessary to achieve the results of the Ph.D., other publications were also made as a way to explore and study parallel ideas and experiment with different technologies besides the ones studied in the context of the Ph.D., namely in the dissemination of results in various projects such as the FoodFriend project³ (in which a coaching system to support diabetic patients regarding eating habits is currently being developed) or in works produced by supervised students. Below is the complete list of publications made during the development of this thesis.

³ <https://itea4.org/project/food-friend.html>

1. B. Teixeira, D. Martinho, P. Novais, J. Corchado, and G. Marreiros, "Diabetic-Friendly Multi-agent Recommendation System for Restaurants Based on Social Media Sentiment Analysis and Multi-criteria Decision Making," in *Progress in Artificial Intelligence: 21st EPIA Conference on Artificial Intelligence, EPIA 2022, Lisbon, Portugal, August 31–September 2, 2022, Proceedings, 2022*, pp. 361-373: Springer. [107]
2. C. Antelo, D. Martinho, and G. Marreiros, "A Review on Supervised Learning Methodologies for Detecting Eating Habits of Diabetic Patients," in *Progress in Artificial Intelligence: 21st EPIA Conference on Artificial Intelligence, EPIA 2022, Lisbon, Portugal, August 31–September 2, 2022, Proceedings, 2022*, pp. 374-386: Springer [108]
3. D. Martinho *et al.*, "An architecture for a Coaching System to Support Type 2 Diabetic Patients", in *Ambient Intelligence – Software and Applications – 13th International Symposium on Ambient Intelligence, 2023*, pp. 167-178: Springer. [109]
4. V. Crista, D. Martinho, J. Meira, J. Carneiro, J. Corchado, and G. Marreiros, "A Hybrid Model to Classify Physical Activity Profiles," in *Highlights in Practical Applications of Agents, Multi-Agent Systems, and Complex Systems Simulation. The PAAMS Collection: International Workshops of PAAMS 2022, L'Aquila, Italy, July 13–15, 2022, Proceedings, 2022*, pp. 268-278: Springer. [110]
5. Pinto, D. Martinho, A. Vieira, A. Ramalho, and A. Freitas, "Recommendation systems in the context of diabetes mellitus type 2: a bibliometric analysis," in *Information Systems and Technologies: WorldCIST 2022, Volume 1*: Springer, 2022, pp. 681-691. [111]
6. Pinto *et al.*, "Improving the lifestyle behavior of type 2 diabetes mellitus patients using a mobile application," in *2022 IEEE Symposium on Computers and Communications (ISCC), 2022*, pp. 1-5: IEEE. [112]

7. C. L. Martins, D. Martinho, G. Marreiros, L. Conceição, L. Faria, and R. S. de Almeida, "Artificial Intelligence in Digital Mental Health," in *Digital Therapies in Psychosocial Rehabilitation and Mental Health*: IGI Global, 2022, pp. 201-225. [113]

3.3.2 Participation and Organization of Events

During this Ph.D., it was possible to participate in and organize scientific events as a scientific reviewer and presenter, which allowed me to exchange ideas and receive feedback from other researchers with different backgrounds, cultures, and points of view.

Organization of Events

1. Workshop on Decision Support, Recommendation, and Persuasion in Artificial Intelligence (DeRePAI 2021) aims to be a discussion forum on the latest trends and ongoing challenges in the application of artificial intelligence technologies in the areas of decision-support, recommendation, and persuasion to discuss strategies to facilitate the decision/choice process by individuals and groups. Participated as a member of the organizing committee;
2. Workshop on Decision Support, Recommendation, and Persuasion in Artificial Intelligence (DeRePAI 2022) aims to be a discussion forum on the latest trends and ongoing challenges in the application of artificial intelligence technologies in the areas of decision-support, recommendation, and persuasion to discuss strategies to facilitate the decision/choice process by individuals and groups. Participated as a member of the organizing committee.

Participation in Events

1. DeepLearn 2022 Spring, 5th International School on Deep Learning, 2022, Guimarães, Portugal;

2. Sistemas inteligentes y ciberseguridad, 2022, Online;
3. La Inteligencia Artificial Al Servicio de La Automática, 2022, Online;
4. Jornada de Seguimiento de la Actividad Investigador, 2022, Online;
5. International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS), 2022, L'Aquila, Italy;
6. Encontro Português de Inteligência Artificial (EPIA), 2022, Lisboa, Portugal;
7. International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS), 2021, Salamanca, Spain;
8. Encontro Português de Inteligência Artificial (EPIA), 2021, Online;
9. Encontro Português de Inteligência Artificial (EPIA), 2019, Vila Real, Portugal;
10. Distributed Computing and Artificial Intelligence (DCAI), 2018, Toledo, Spain;
11. International Conference on Practical Applications of Agents and Multi-Agent Systems (PAAMS), 2018, Toledo, Spain;
12. The role of advanced eInfrastructure for research in the digital transformation era, 2018, Salamanca, Spain.

3.3.3 Invited Presentations

Presentations were also conducted outside conferences and scientific events, specifically in an academic context. There were opportunities to exchange some of the

work done with students and colleagues in scientific community events and master classes.

1. Consortium of Applied Research and Professional Education (CARPE) Special Interest Group “Data Science & AI” Class entitled “Improving Personalized Elderly Care - An Approach Using Cognitive Agents to Better Assist Elderly People”, on 17th June 2022 (Online);
2. Enterprise Information Systems Master Class given for Master in Informatics Engineering students at School of Engineering of Polytechnic Institute of Porto entitled “A Systematic Review of Gamification Techniques Applied to Elderly Care”, on 7th March 2023 (Online);
3. Research and Innovation in Artificial Intelligence Master Class given for Master in Artificial Intelligence students at School of Engineering of Polytechnic Institute of Porto entitled “A Systematic Review of Gamification Techniques Applied to Elderly Care”, on 18th October 2022 (Online);
4. Research and Innovation in Artificial Intelligence Master Class given for Master in Artificial Intelligence students at School of Engineering of Polytechnic Institute of Porto entitled “A Systematic Review of Gamification Techniques Applied to Elderly Care”, on 4th November 2021 (Online).

3.3.4 Lecturing

During this Ph.D., different lectured courses were given as guest professor at the School of Engineering in the Polytechnic Institute of Porto. The list of lectured courses was the following:

1. Advanced Algorithms (2019-2021), Laboratory Practice;
2. Agent-Based Systems (2021-2023), Recitations and Laboratory Practice;

3. Planning and Decision Support (2021-2022), Laboratory Practice;
4. Knowledge Engineering (2021-2023), Laboratory Practice.

3.3.5 Supervision of Students

During this Ph.D., there was the opportunity to supervise master and ungraduated students from the Institute Polytechnic of Porto along with Professor Maria Goreti Carvalho Marreiros, some of which developed work in the context of this thesis while others developed work in the healthcare area. These students' respective dissertation titles were the following:

1. Vítor Rafael Palmeiro Crista (2021), Graduation in Computer Engineering, Dissertation: “Desenvolvimento de uma aplicação gamificada para suporte de utilizadores idosos”;
2. José Diogo Teixeira Pessoa (2021), Graduation in Computer Engineering, Dissertation: “Desenvolvimento de uma aplicação gamificada para suporte de utilizadores idosos”;
3. Hugo Filipe Gonçalves Frias (2021), Graduation in Computer Engineering, Dissertation: “Aplicação de Registo Nutricional”;
4. Ana Isabel Aires Vieira (2019), Masters in Computer Engineering, Dissertation: “Desenvolvimento de um Sistema para Suporte Individualizado Inteligente a Pacientes com Doença Respiratória Obstrutiva Crónica”;
5. Nair Gomes D’Araújo (2022), Masters in Biomedical Engineering, Dissertation title: “Development of a Nutritional and Physical Activity Plan Recommendation System for Patients with Type 2 diabetes.”; João Godinho
6. João Ferreira Trindade Mendes Godinho (2020), Masters in Computer Engineering and Medical Instrumentation, Dissertation title: “Mobile

Application for register of nutrition and physical activity for patients with type 2 diabetes mellitus.”;

7. Sara Catarina Mendes Batista (2020), Masters in Computer Engineering and Medical Instrumentation, Dissertation title: “Nutritional Recommender System for Patients with Type 2 Diabetes Mellitus.”;
8. Bruno César Jantarada Teixeira (2022), Masters in Artificial Intelligence Engineering, Dissertation title: “Diabetic-Friendly Multi-Agent Recommendation System for Restaurants based on Social Media Sentiment Analysis and Multi-Criteria Decision Making”;
9. Ana Catarina Lopes Antelo (2022), Masters in Artificial Intelligence Engineering, Dissertation title: “Visão computacional para detecção de hábitos alimentares”;
10. João Carlos Campos Moreira da Silva (2022), Masters in Biomedical Engineering, Dissertation title: “Reconhecimento e recomendação de hábitos alimentares de pacientes diabéticos do tipo 2”.

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APPENDIX A. CORE PUBLICATIONS

A CONCEPTUAL APPROACH TO ENHANCE THE WELL-BEING OF ELDERLY PEOPLE

TITLE	A Conceptual Approach to Enhance the Well-Being of Elderly People
AUTHORS	Diogo Martinho, João Carneiro, Paulo Novais, José Neves, Juan Corchado, Goreti Marreiros
PUBLICATION TYPE	Conference Proceedings
CHAPTER	Progress in Artificial Intelligence
SERIES	Lecture Notes in Computer Science
CONFERENCE	19th EPIA Conference on Artificial Intelligence
PUBLISHER	Springer
VOLUME	11805
PAGES	50-61
YEAR	2019
ONLINE ISBN	978-3-030-30244-3
PRINT ISBN	978-3-030-30243-6
URL	https://link.springer.com/chapter/10.1007/978-3-030-30244-3_5
STATE	Published
SCIMAGO JOURNAL RANK (2019)	0.427, Computer Science (Q2), Theoretical Computer Science (Q3)
INDEXATION	ACM Digital Library, Chemical Abstracts Service (CAS), DBLP, EI Compendex, INSPEC, Japanese Science and Technology Agency (JST), Norwegian Register for Scientific Journals and Series, SCImago, SCOPUS, WTI Frankfurt eG, zbMATH

Contribution of the doctoral candidate

The doctoral candidate, Diogo Emanuel Pereira Martinho, declares to be the main author and the major contributor to the paper *A Conceptual Approach to Enhance the Well-Being of Elderly People*.

Resumen

El número de personas ancianas que viven solas está aumentando. En consecuencia, se han realizado numerosos trabajos de investigación para abordar este problema con el fin de proponer soluciones que puedan mejorar la calidad de vida de las personas ancianas. La mayoría de ellos se han centrado en abordar problemas objetivos como la pérdida de memoria o la detección de caídas. En este documento, proponemos un enfoque conceptual de un sistema que pretende mejorar el sentido diario del bienestar del usuario. Para ello, nuestra propuesta consiste en un sistema que funciona como una red social y una aplicación de reloj inteligente que funciona de manera discreta y recopila los datos fisiológicos del usuario. Además, debatimos sobre cómo se podrían implementar características importantes, como detectar los estados afectivos del usuario y potenciar su memoria. Nuestro estudio muestra que todavía existen algunas limitaciones importantes que afectan al éxito de las aplicaciones construidas en el contexto del cuidado de los ancianos y que están relacionadas principalmente con la precisión y la usabilidad de este tipo de sistema. Sin embargo, creemos que con nuestro enfoque podremos abordar algunas de esas limitaciones y definir un sistema que pueda mejorar el bienestar de las personas ancianas y mejorar sus capacidades cognitivas.

DEFINING AN ARCHITECTURE FOR A COACHING MODULE TO SUPPORT SELF-MONITORING OF CHRONIC OBSTRUCTIVE RESPIRATORY DISEASES

TITLE	Defining an Architecture for a Coaching Module to Support Self-Monitoring of Chronic Obstructive Respiratory Diseases
AUTHORS	Ana Vieira, Diogo Martinho, Constantino Martins, Ana de Almeida, Goreti Marreiros
PUBLICATION TYPE	Conference Proceedings
CHAPTER	Health Informatics Vision: From Data via Information to Knowledge
SERIES	Studies in Health Technology and Informatics
CONFERENCE	17th International Conference on Informatics, Management, and Technology in Health Care
PUBLISHER	IOS Press
VOLUME	262
PAGES	130-133
YEAR	2019
ONLINE ISBN	978-1-61499-987-4
PRINT ISBN	978-1-61499-986-7
URL	https://ebooks.iospress.nl/volumearticle/51696
STATE	Published
SCIMAGO JOURNAL RANK (2019)	0.267, Biomedical Engineering (Q3), Health Informatics (Q3), Health Information Management (Q3)
INDEXATION	Scopus, Web of Science

Contribution of the doctoral candidate

The doctoral candidate, Diogo Emanuel Pereira Martinho, declares to be the second author and the second major contributor to the paper *Defining an Architecture for a Coaching Module to Support Self-Monitoring of Chronic Obstructive Respiratory Diseases*.

Resumen

Con el tiempo, ha habido un aumento en el número de personas afectadas por enfermedades respiratorias obstructivas crónicas, lo que ha generado una carga para los proveedores de atención médica. Siguiendo el crecimiento de las tecnologías de la información, se ha buscado el desarrollo de soluciones innovadoras que ayuden a monitorear y tratar a los pacientes. En este trabajo se propone la arquitectura de un módulo de entrenamiento para integrarse en el sistema desarrollado por el proyecto PHE. Con el objetivo de mejorar la condición de salud de los pacientes proporcionando herramientas de medición y monitoreo innovadoras e inteligentes para la atención médica preventiva y permitir soluciones asequibles con una mayor participación del paciente. Con este trabajo, definimos la arquitectura de un módulo que puede generar recomendaciones adaptadas a cada paciente. Al hacerlo, creemos que es posible motivar la adopción de comportamientos que beneficien la condición de salud del paciente y disminuyan el riesgo de complicaciones asociadas a la enfermedad.

A MULTIPLE CRITERIA DECISION ANALYSIS FRAMEWORK FOR DISPERSED GROUP DECISION- MAKING CONTEXTS

TITLE	A Multiple Criteria Decision Analysis Framework for Dispersed Group Decision-Making Contexts
AUTHORS	João Carneiro, Diogo Martinho, Patrícia Alves, Luís Conceição, Goreti Marreiros, Paulo Novais
PUBLICATION TYPE	Journal
PUBLICATION NAME	Applied Sciences
PUBLISHER	MDPI
VOLUME	10
NUMBER	13
PAGES	4614-4640
YEAR	2020
MONTH	July
ONLINE ISSN	2076-3417
URL	https://www.mdpi.com/2076-3417/10/13/4614/htm
STATE	Published
SCIMAGO JOURNAL RANK (2020)	0.435, Computer Science and Applications (Q2), Engineering (Miscellaneous) (Q2), Fluid Flow and Transfer Processes (Q2), Instrumentation (Q2), Material Science (Miscellaneous) (Q2), Process Chemistry and Technology (Q2)
JCR IMPACT FACTOR (2020)	2.679, Chemistry, Multidisciplinary (Q3), Engineering, Multidisciplinary (Q2), Materials Science, Multidisciplinary (Q3), Physics, Applied (Q2),

Contribution of the doctoral candidate

The doctoral candidate, Diogo Emanuel Pereira Martinho, declares to be the main author and the major contributor to the paper *A Multiple Criteria Decision Analysis Framework for Dispersed Group Decision-Making Contexts*

Resumen

Apoyar los procesos de toma de decisiones en grupo cuando los participantes están dispersos es una tarea compleja. Los mayores desafíos están relacionados con las limitaciones de comunicación que impiden que los tomadores de decisiones aprovechen los beneficios asociados con los procesos de toma de decisiones en grupo presenciales. Se han aplicado varios enfoques que pretenden ayudar a los grupos dispersos a tomar decisiones en Sistemas de Soporte a la Toma de Decisiones en Grupo. Sin embargo, las estrategias para respaldar a los tomadores de decisiones en el razonamiento, comprensión de las razones detrás de las diferentes recomendaciones y promoción de la calidad de la decisión son muy limitadas. En este trabajo, proponemos un Marco de Análisis de Decisiones de Múltiples Criterios que pretende superar esas limitaciones a través de un conjunto de funcionalidades que pueden utilizarse para respaldar a los tomadores de decisiones en la toma de decisiones más informadas, consistentes y satisfactorias. Estas funcionalidades se exponen a través de un microservicio, que forma parte de un Sistema de Soporte a la Toma de Decisiones en Grupo basado en el consenso y es utilizado por agentes de software autónomos para respaldar a los tomadores de decisiones de acuerdo con sus necesidades/intereses específicos. Concluimos que el marco propuesto facilita en gran medida la definición de procedimientos importantes, permitiendo a los tomadores de decisiones aprovechar la toma de decisiones como grupo y comprender las razones detrás de las diferentes recomendaciones y propuestas.

A DEFINITION OF A COACHING PLAN TO GUIDE PATIENTS WITH CHRONIC OBSTRUCTIVE RESPIRATORY DISEASES

TITLE	A Definition of a Coaching Plan to Guide Patients with Chronic Obstructive Respiratory Diseases
AUTHORS	Diogo Martinho, Ana Vieira, João Carneiro, Constantino Martins, Ana Almeida, Goreti Marreiros
PUBLICATION TYPE	Conference Proceedings
CHAPTER	WorldCIST 2020: Trends and Innovations in Information Systems and Technologies
SERIES	Advances in Intelligent Systems and Computing
CONFERENCE	8th World Conference on Information Systems and Technologies
PUBLISHER	Springer
VOLUME	1161
PAGES	54-64
YEAR	2020
ONLINE ISBN	978-3-030-45697-9
PRINT ISBN	978-3-030-45696-2
URL	https://link.springer.com/chapter/10.1007/978-3-030-45697-9_6
STATE	Published
INDEXATION	BFI List, DBLP, INSPEC, Japanese Science and Technology Agency (JST), Norwegian Register for Scientific Journals and Series, WTI Frankfurt eG, zbMATH

Contribution of the doctoral candidate

The doctoral candidate, Diogo Emanuel Pereira Martinho, declares to be the main author and the major contributor to the paper *A Definition of a Coaching Plan to Guide Patients with Chronic Obstructive Respiratory Diseases*.

Resumen

Con un aumento notable en el número de personas con enfermedades respiratorias obstructivas crónicas, la efectividad de los sistemas de atención médica tradicionales ha empeorado significativamente en los últimos años. Existe la oportunidad de desarrollar soluciones personalizadas y de bajo costo que puedan capacitar a los pacientes para autoadministrar y autocontrolar su condición de salud. En este contexto, se encuentra presente el proyecto PHE, cuyo objetivo principal es desarrollar soluciones de entrenamiento para la monitorización remota de pacientes que puedan proporcionarse exclusivamente a través del uso de teléfonos inteligentes. En este trabajo, exploramos cómo los pacientes con enfermedades respiratorias obstructivas crónicas pueden adoptar comportamientos más saludables siguiendo planes de entrenamiento personalizados para la atención médica utilizados en su vida diaria. Explicamos cómo se puede definir un plan de entrenamiento para guiar al paciente y exploramos los mecanismos necesarios para operar automáticamente y adaptarse según las interacciones entre el paciente y el sistema. Como resultado, creemos que es posible mejorar la experiencia y el compromiso del usuario con el sistema desarrollado y, por lo tanto, mejorar su condición de salud.

A SYSTEMATIC REVIEW OF GAMIFICATION TECHNIQUES APPLIED TO ELDERLY CARE

TITLE	A systematic review of gamification techniques applied to elderly care
AUTHORS	Diogo Martinho, João Carneiro, Juan M Corchado, Goreti Marreiros
PUBLICATION TYPE	Journal
PUBLICATION NAME	Artificial Intelligence Review
PUBLISHER	Springer
VOLUME	53
NUMBER	7
PAGES	4863-4901
YEAR	2020
MONTH	February
ONLINE ISSN	1573-7462
PRINT ISSN	0269-2821
URL	https://link.springer.com/article/10.1007/s10462-020-09809-6
STATE	Published
SCIMAGO JOURNAL RANK (2020)	1.195, Artificial Intelligence (Q1), Linguistics and Language (Q1)
JCR IMPACT FACTOR (2020)	8.139, Computer Science, Artificial Intelligence (Q1)

Contribution of the doctoral candidate

The doctoral candidate, Diogo Emanuel Pereira Martinho, declares to be the main author and the major contributor to the paper *A Systematic Review of Gamification Techniques Applied to Elderly Care*.

Resumen

La proporción de la población mundial que envejece está aumentando rápidamente en las últimas décadas. Con los recientes avances vistos en tecnologías de información y comunicación, ha habido grandes preocupaciones acerca de desarrollar servicios de atención médica personalizados que puedan garantizar las condiciones de vida y el envejecimiento activo de las personas ancianas. Entre estas tecnologías, destacamos y revisamos en este trabajo el estado actual de la gamificación y las técnicas relacionadas aplicadas al contexto del cuidado de ancianos. Se definieron seis preguntas de investigación para proporcionar una visión general sobre el estado actual en el desarrollo de sistemas gamificados para el cuidado de ancianos a través de la identificación de tipos de fuente de publicación, áreas de investigación, grupos objetivo, elementos de diseño de juegos y tecnologías empleadas y problemas y beneficios observados del uso de la gamificación en este contexto. Los resultados han mostrado una gran diversidad en los tipos de fuentes de publicación y áreas de investigación, incluso dentro del dominio de la salud. Se identificaron diferentes grupos objetivo en función del entorno circundante y las capacidades físicas y cognitivas de la persona anciana. Se destacan como los elementos de diseño de juego más relevantes y utilizados en este contexto la retroalimentación, la progresión, las recompensas y el aumento de la interacción social. Las características tecnológicas observadas incluyen sistemas de autogestión, dispositivos portátiles, robots físicos, consolas y tecnologías portables. El uso de técnicas de gamificación para apoyar a las personas ancianas ha demostrado ser beneficioso para mejorar el bienestar, así como el estado físico, cognitivo, social y emocional de la persona anciana. Los desafíos actuales están relacionados principalmente con la necesidad de que los servicios de atención médica tradicionales integren técnicas de gamificación para mejorar la atención médica personalizada y responder a diferentes necesidades y adaptar el apoyo proporcionado según las capacidades individuales de las personas ancianas. Los hallazgos presentados en esta revisión sistemática de la literatura deberían ser considerados en el desarrollo de futuras soluciones de atención médica personalizadas para personas ancianas al adaptar el apoyo proporcionado según los intereses, capacidades, necesidades y contextos asociados a la persona anciana como un medio para mejorar la

independencia, la salud y el bienestar, capturar el interés y el compromiso positivo, facilitar la interacción social y disminuir el impacto de muchas condiciones médicas diferentes que afectan a las personas ancianas.

A HYBRID MODEL TO CLASSIFY PATIENTS WITH CHRONIC OBSTRUCTIVE RESPIRATORY DISEASES

TITLE	A Hybrid Model to Classify Patients with Chronic Obstructive Respiratory Diseases
AUTHORS	Diogo Martinho, Alberto Freitas, Ana Sá-Sousa, Ana Vieira, Jorge Meira, Constantino Martins, Goreti Marreiros
PUBLICATION TYPE	Journal
PUBLICATION NAME	Journal of Medical Systems
PUBLISHER	Springer
VOLUME	45
NUMBER	31
PAGES	1-11
YEAR	2021
MONTH	January
ONLINE ISSN	1573-689X
URL	https://link.springer.com/article/10.1007/s10916-020-01704-5
STATE	Published
SCIMAGO JOURNAL RANK (2021)	1.131, Health Informatics (Q1), Health Information Management (Q1), Information Systems (Q1), Medicine (miscellaneous) (Q1)
JCR IMPACT FACTOR (2021)	4.920, Health Care Sciences & Services (Q1), Medical Informatics (Q2)

Contribution of the doctoral candidate

The doctoral candidate, Diogo Emanuel Pereira Martinho, declares to be the main author and the major contributor to the paper *A Hybrid Model to Classify Patients with Chronic Obstructive Respiratory Diseases*.

Resumen

En las últimas décadas, se ha observado un aumento en la población envejecida y en enfermedades relacionadas con la edad, junto con un aumento en los costos de la atención médica. Por lo tanto, se necesitan nuevas soluciones para proporcionar un apoyo más eficiente y asequible a este grupo de pacientes. Tales soluciones nunca deben descartar al usuario y, en su lugar, deben centrarse en promover estilos de vida más saludables y proporcionar herramientas para la participación activa de los pacientes en el tratamiento y manejo de sus enfermedades. En este sentido, el proyecto Personal Health Empowerment (PHE) presentado en este artículo tiene como objetivo empoderar a los pacientes para que monitoreen y mejoren su salud, utilizando datos personales y coaching asistido por tecnología. El trabajo descrito en este artículo se enfoca en definir un enfoque de modelado de usuario en pacientes con enfermedades respiratorias obstructivas crónicas utilizando un enfoque de modelado híbrido para identificar diferentes grupos de usuarios. Se generó un modelo de clasificación con una precisión de predicción del 90,4% combinando técnicas de clustering jerárquico aglomerativo y clasificación de árboles de decisión. Además, este modelo identificó 5 grupos que describen características de 5 tipos diferentes de usuarios según 7 reglas generadas. Con el enfoque de modelado definido en este estudio, se construirá una solución de coaching personalizada considerando pacientes con diferentes necesidades y capacidades y adaptando el apoyo proporcionado, lo que permitirá el reconocimiento de signos tempranos de exacerbaciones y el auto-monitoreo objetivo y tratamiento de la enfermedad. El factor novedoso de este enfoque reside en la posibilidad de integrar tecnologías de coaching personalizado adaptadas a cada tipo de usuario dentro de una aplicación basada en smartphone, lo que resulta en una alternativa confiable y asequible para que los pacientes manejen su enfermedad.

A REINFORCEMENT LEARNING APPROACH TO IMPROVE USER ACHIEVEMENT OF HEALTH-RELATED GOALS

TITLE	A Reinforcement Learning Approach to Improve User Achievement of Health-Related Goals
AUTHORS	Diogo Martinho, João Carneiro, José Neves, Paulo Novais, Juan Corchado, Goreti Marreiros
PUBLICATION TYPE	Conference Proceedings
CHAPTER	Progress in Artificial Intelligence
SERIES	Lecture Notes in Artificial Intelligence
CONFERENCE	20th EPIA Conference on Artificial Intelligence
PUBLISHER	Springer
VOLUME	12981
PAGES	266-277
YEAR	2021
ONLINE ISBN	978-3-030-86230-5
PRINT ISBN	978-3-030-86229-9
URL	https://link.springer.com/chapter/10.1007/978-3-030-86230-5_21
STATE	Published
SCIMAGO JOURNAL RANK (2021)	0.407, Computer Science (Q2), Theoretical Computer Science (Q3)
INDEXATION	ACM Digital Library, Chemical Abstracts Service (CAS), DBLP, EI Compendex, INSPEC, Japanese Science and Technology Agency (JST), Norwegian Register for Scientific Journals and Series, SCImago, SCOPUS, WTI Frankfurt eG, zbMATH

Contribution of the doctoral candidate

The doctoral candidate, Diogo Emanuel Pereira Martinho, declares to be the main author and the major contributor to the paper *A Reinforcement Learning Approach to Improve User Achievement of Health-Related Goals*.

Resumen

La demanda e interés por soluciones de atención médica personalizadas, eficientes y económicas ha aumentado significativamente en la última década para superar las principales limitaciones de los enfoques tradicionales de atención médica existentes. Esta nueva tendencia se basa en la definición de mecanismos inteligentes que puedan persuadir al usuario final a lograr resultados relacionados con la salud y, en última instancia, mejorar su estado de salud y bienestar. En este sentido, el trabajo propuesto aquí explora un sistema multiagente compuesto por agentes personales que siguen las preferencias del usuario y un agente de coaching que se basa en un enfoque de aprendizaje por refuerzo para identificar los mensajes más impactantes para persuadir a cierto agente a seguir los objetivos relacionados con la salud establecidos. Para validar el sistema propuesto, se realizaron una serie de simulaciones considerando diferentes tipos de mensajes persuasivos y se identificó la secuencia más adecuada de mensajes que pueden persuadir a diferentes usuarios a lograr objetivos relacionados con la salud basados en sus preferencias.

AN INTELLIGENT COACHING PROTOTYPE FOR ELDERLY CARE

TITLE	An Intelligent Coaching Prototype for Elderly Care
AUTHORS	Diogo Martinho, Vítor Crista, João Carneiro, Juan Manuel Corchado, Goreti Marreiros
PUBLICATION TYPE	Journal
PUBLICATION NAME	Electronics
PUBLISHER	MDPI
VOLUME	11 (3)
NUMBER	460
PAGES	1-13
YEAR	2022
MONTH	February
ONLINE ISSN	2079-9292
URL	https://www.mdpi.com/2079-9292/11/3/460
STATE	Published
SCIMAGO JOURNAL RANK (2021)	0.59, Computer Networks and Communications (Q2), Control and Systems Engineering (Q2), Electrical and Electronic Engineering (Q2), Hardware and Architecture (Q2), Signal Processing (Q2)
JCR IMPACT FACTOR (2021)	2.690, Computer Science, Information Systems (Q3), Engineering, Electrical & Electronic (Q3), Physics, Applied (Q3)

Contribution of the doctoral candidate

The doctoral candidate, Diogo Emanuel Pereira Martinho, declares to be the main author and the major contributor to the paper *An Intelligent Coaching Prototype for Elderly Care*.

Resumen

El problema del envejecimiento en el mundo está impulsando nuevas formas sostenibles de apoyar a las personas ancianas. Por lo tanto, es importante promover formas personalizadas e inteligentes de asegurar el envejecimiento activo y saludable de la población. Los avances tecnológicos han llevado al desarrollo de sistemas de atención médica personalizados, capaces de monitorear y brindar retroalimentación sobre diferentes aspectos que pueden mejorar la salud de la persona anciana. Además, es fundamental definir estrategias motivacionales para persuadir a la persona anciana a adoptar hábitos más saludables y mantenerse conectada con dichos sistemas. En este trabajo se presenta un sistema de coaching especialmente diseñado para apoyar a las personas ancianas y motivarlas a adoptar formas más saludables de vida. Para ello, se desarrolla una aplicación de coaching que utiliza tanto un asistente virtual cognitivo para interactuar directamente con la persona anciana y brindar retroalimentación sobre su estado de salud actual, como varias técnicas de gamificación para motivar a la persona anciana a mantenerse comprometida con la aplicación. Además, se llevaron a cabo una serie de simulaciones para validar el sistema propuesto en términos del apoyo y la retroalimentación proporcionados al usuario de acuerdo con su progreso y mediante las interacciones con el asistente cognitivo.

APPENDIX B. PREPRINT

EFFECTS OF A GAMIFIED AGENT-BASED SYSTEM FOR PERSONALIZED ELDERLY CARE: A PILOT USABILITY STUDY

TITLE	Effects of a Gamified Agent-Based System for Personalized Elderly Care: A Pilot Usability Study
AUTHORS	Diogo Martinho, Vítor Crista, João Carneiro, Kenji Matsui, Juan Manuel Corchado, Goreti Marreiros
PUBLICATION TYPE	Journal
PUBLICATION NAME	JMIR Serious Games
PUBLISHER	JMIR
PAGES	1-14
YEAR	2023
MONTH	April
ONLINE ISSN	2079-9292
STATE	Submitted
SCIMAGO JOURNAL RANK (2021)	0.58, Biomedical Engineering (Q2), Physical Therapy, Sports Therapy and Rehabilitation (Q2), Physical and Mental Health (Q2), Rehabilitation (Q1)
JCR IMPACT FACTOR (2021)	3.364, Health Care Sciences & Services (Q2), Medical Informatics (Q3), Public, Environmental & Occupational Health (Q2)

Contribution of the doctoral candidate

The doctoral candidate, Diogo Emanuel Pereira Martinho, declares to be the main author and the major contributor to the paper *Effects of a Gamified Agent-Based System for Personalized Elderly Care: A Pilot Usability Study*.

Resumen

Antecedentes: En las últimas décadas, el porcentaje global de personas ancianas ha aumentado significativamente. El uso de tecnologías de la información y la comunicación se ha vuelto esencial para motivar a las personas ancianas a adoptar formas de vida más saludables. En este trabajo se presenta un servicio de atención médica personalizado de coaching que puede garantizar las condiciones de vida y el envejecimiento activo de las personas ancianas. Entre estas tecnologías, se destaca el uso de técnicas de gamificación y asistentes cognitivos diseñados para apoyar a las personas ancianas y se presenta una aplicación que combina tanto un asistente virtual cognitivo para interactuar directamente con la persona anciana y brindar retroalimentación sobre su estado de salud actual, como varias técnicas de gamificación para motivar a la persona anciana a mantenerse comprometida con la aplicación y a adoptar hábitos diarios más saludables.

Objetivo: Este estudio piloto tuvo como objetivo investigar la viabilidad y la facilidad de uso de un sistema basado en agentes gamificado para personas ancianas y obtener resultados preliminares sobre la efectividad de la intervención en relación con los resultados de salud relacionados con la actividad física.

Métodos: El estudio se diseñó como un estudio de intervención que compara los resultados de la prueba previa y posterior. El sistema basado en agentes gamificado propuesto fue utilizado por 12 participantes durante 7 días (1 semana) y se recopilaron datos de conteo de pasos con acceso a la API de Google Fit. Luego, se compararon los datos de conteo de pasos después de la intervención con los datos de conteo de pasos promedio antes de la intervención (valores diarios promedio durante un período de 4 semanas previas a la intervención). Se utilizó la prueba t de Student para determinar la relación entre las variables dependientes e independientes. La facilidad de uso se midió utilizando el cuestionario System Usability Score, que fue respondido por 8 de los 12 participantes en el estudio.

Resultados: Los resultados posteriores a la prueba fueron significativamente altos en términos de cambios antes y después de la prueba ($P = 0,017$; prueba t de Student), con un tamaño de efecto moderado (D de Cohen de 0,77). En cuanto a la facilidad de uso, la aplicación desarrollada obtuvo una puntuación media de usabilidad de 78.

Conclusiones: El piloto presentado fue validado mostrando los efectos positivos en la salud del uso de técnicas de gamificación junto con el uso de un asistente cognitivo virtual. Además, las métricas de usabilidad consideradas para este estudio confirmaron la alta adherencia e interés de la mayoría de los participantes en el piloto.

APPENDIX C. CONCLUSIONS IN SPANISH

CONCLUSIONES PRINCIPALES, CONTRIBUCIONES Y TRABAJO FUTURO

Con el aumento del porcentaje de personas ancianas que viven hoy en día, se están explorando nuevos enfoques y estrategias inteligentes con el objetivo de permitir que este grupo de personas más frágiles permanezca activo y enfrente una disminución menos impactante en su condición de salud y bienestar mientras envejecen. En este contexto, el desarrollo de sistemas de atención médica personalizados capaces de apoyar a las personas ancianas en su vida diaria se vuelve claramente necesario, especialmente para aprovechar los últimos avances tecnológicos combinados con estrategias exitosas de compromiso para persuadir y motivar a las personas ancianas hacia cambios de comportamiento positivos. Entre todas las diferentes ideas y propuestas existentes, muchos estudios destacan el potencial de considerar mecanismos más interactivos para llamar la atención del usuario, con resultados ya exitosos en cuanto al uso de sistemas gamificados en el contexto de la atención médica y más específicamente en el contexto de la atención a personas ancianas. Estos sistemas, empoderados con características similares a los juegos, pueden ofrecer experiencias más atractivas y entretenidas para captar el interés del usuario utilizando características que contribuyan tanto a la estimulación física, cognitiva, emocional e incluso social, lo que a su vez responde a la preocupación por un envejecimiento saludable.

El trabajo de tesis presentado en este manuscrito fue fuertemente inspirado por estos puntos, y se realizó una importante investigación para comprender cómo un sistema de atención médica gamificado diseñado con técnicas particulares de gamificación y estrategias persuasivas y de comportamiento podría contribuir a mejorar la salud y el bienestar de las personas ancianas. Como tal, la hipótesis principal de investigación derivada aquí estudiada tuvo como objetivo responder si el uso de un agente cognitivo que procesa datos relacionados con la persona anciana, como la condición de salud y el comportamiento, puede adaptar la interacción y el apoyo proporcionado para satisfacer mejor los intereses y necesidades de la persona anciana. Para ello, se desarrolló una aplicación de coaching gamificado (llamada CoaFEld) con diferentes elementos para motivar al usuario y mejorar su experiencia, que considera un asistente cognitivo para interactuar directamente con la persona anciana y proporcionarle comentarios relacionados con el progreso de la condición de salud. Se dan diferentes señales emocionales para representar el progreso del usuario, que pueden ser cada vez más positivas a medida que mejora la condición de salud del usuario o cada vez más negativas a medida que disminuye su condición de salud.

Los resultados obtenidos muestran que fue posible validar el impacto del asistente virtual y la solución gamificada en general desarrollada dentro de la aplicación CoaFEld con la participación de diferentes usuarios de 55 años o más y se obtuvieron resultados significativos en términos de usabilidad, aceptabilidad y efectividad del enfoque considerado. Específicamente, el estudio de validación destacó la importancia y el efecto positivo de combinar tanto el uso de elementos gamificados como una estrategia de compromiso social con un asistente virtual para traducir el progreso del usuario en un entorno de atención médica. Los resultados obtenidos favorecieron el uso de la aplicación CoaFEld con una mejora en los resultados de salud después de la intervención, en comparación con los datos de salud obtenidos antes de la intervención ($P = 0,017$ calculado con la prueba t de Student cuando $P < 0,05$), con un tamaño del efecto de Cohen D de 0,77, que es moderado pero cercano a un tamaño grande (tamaño del efecto $> 0,8$). Además, los resultados de usabilidad obtenidos a través de la finalización del cuestionario SUS también confirmaron una alta aceptabilidad y usabilidad, con una puntuación media de usabilidad de 78 obtenida junto con

comentarios positivos generales de los participantes expresando su intención de seguir usando la aplicación después de que se completara el período de intervención.

Los hallazgos resultantes del desarrollo y validación de CoaFeld, con el logro de los objetivos establecidos para responder a la hipótesis de investigación presentada, han contribuido a resultados significativos en el estado del arte de los campos de inteligencia artificial y atención médica. Las principales contribuciones al área de inteligencia artificial se dieron principalmente en los campos de aprendizaje automático y sistemas multiagente, mientras que en el contexto de la atención médica se relacionaron específicamente con el cuidado de ancianos y la mejora del bienestar y la condición de salud a través de la estimulación cognitiva, física, emocional y social. Se publicaron ocho artículos científicos principales como resultado de este trabajo de doctorado, y la contribución de este trabajo hacia el logro del proyecto AIRDOC y los objetivos relacionados son indicadores sólidos de la importancia de los hallazgos logrados.

Como trabajo futuro, tenemos la intención de mejorar el sistema de entrenamiento propuesto para considerar escenarios de mayor complejidad y personas con comportamientos y formas de vida más complejos. Además, pretendemos incorporar nuestro enfoque con dispositivos que puedan proporcionar datos en tiempo real y monitorear directamente la condición de salud del paciente, como pulseras inteligentes, para medir la precisión y el impacto de cada interacción realizada entre el sistema propuesto y la persona anciana. También tenemos la intención de mejorar nuestro sistema gamificado mediante (1) la inclusión de usuarios adicionales (familiares) que puedan proporcionar contenido y recompensas adicionales a la persona anciana; (2) establecer planes cognitivos que puedan evaluarse específicamente en función de los resultados cognitivos derivados del uso de la aplicación.

Otro punto de mejora es obtener más resultados y conclusiones en términos de usabilidad y aceptabilidad. Como se explica en [9] es necesario estudiar la efectividad del trabajo propuesto junto con personas ancianas de edad avanzada y medir el

rendimiento a largo plazo en comparación con el rendimiento y los resultados a corto plazo ya obtenidos durante un período de una semana.

Finalmente, también sería interesante explorar estrategias más directas para entornos más críticos, especialmente al tratar con individuos muy frágiles y ancianos (en los cuales el uso de una herramienta tecnológica compleja puede resultar abrumador), con el uso de robots in situ que puedan incorporar las tecnologías desarrolladas aquí para ayudar e interactuar con la persona anciana, guiándola hacia la consecución de resultados exitosos en su salud.

Con estos puntos en mente, será posible mejorar cada vez más el enfoque inteligente aquí presentado con mejores herramientas para apoyar a la persona anciana en su vida diaria y fomentar y motivar un envejecimiento activo y saludable.