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Editorial

Special Issue on eHealth Innovative Approaches and Applications

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1. Introduction

Innovative ICT technologies, approaches and applications are becoming increasingly pervasive in several domains, including in medicine and healthcare. In these latter cases, physicians and medical professionals can recently incorporated complex and advanced systems, based on the latest technologies, into their daily routines. Scientific research constantly proposes new approaches and applications with high potential for usage in the eHealth sector. For example, the advent of digitised images in pathology and advances in Artificial Intelligence (AI) have led to an explosion of innovation in the traditional field of pathology, creating what is now described as Computational Pathology [1], which defines new and increasingly effective AI approaches for digital image analysis. Similarly, the pervasive adoption of AI in other medical fields has allowed the definition and implementation of innovative systems to support the work of physicians, medical professionals and policy makers, such as recommender systems [2], smart patient support and remote monitoring systems [3,4]. Another technology that has become increasingly pervasive in medicine in recent years is the Internet of Medical Things (IoMT), which is currently largely adopted in healthcare; this technology is redefining smart healthcare systems and approaches to providing care [5].

Furthermore, the great recent improvements in the field of Natural Language Processing (NLP), with the release of Large Language Models (LLMs) such as ChatGPT, also impacted the biomedical domain, quickly leading to the widespread use of these models in medical research (as in other domains) or in healthcare. Recently, LLMs have provided functional eHealth applications ranging from the development of virtual medical assistants to the acceleration of various benchmarks of several biomedical information tasks, including document classification or relation extraction, exploiting closed-domain models such as BioBERT [6], or BERTMeSH [7]. Examples of further innovative eHealth technologies based on LLMs are smart assistants and question-answering systems, such as Med-PaLM 2 [8], ChatDoctor [9] or MedPrompt [10], which obtain very promising performances and results.

On the other hand, this current revolution in the medical domain, thanks to these new technologies and approaches, has some drawbacks and issues that must be taken into account in order to effectively exploit all its advantages without any risks or problems. eHealth approaches must guarantee the required levels of privacy and security [11–13] during the processing, transmission and sharing of medical and personal information, preventing violations or thefts of patients' sensitive medical data. The scarcity of medical and clinical datasets with high-quality annotations is also a limitation in the development and improvement of innovative eHealth approaches [14–16]. Furthermore, the increasing number of connected medical devices and the complex digital healthcare delivery systems cause several cyber security issues [17,18], due to the increased risk of surface attack. Thus, defining innovative cyber security techniques specifically tailored for the healthcare domain is required. The growing volume of medical data, and their complexity and heterogeneity, pose additional challenges for the effective extraction of valuable insights [19–21]. In

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this case, tailored approaches are also required [22,23]. Moreover, physician, medical professional and patient awareness must be increased, and all parties must be warned of the possibilities and threats inherent to digital medicine [24,25].

In this scenario, it becomes crucial to disseminate the most recent results and enhancements achieved by research in the domain of eHealth. While taking full advantage of the latest advances in ICT approaches applied to the medical sector, their issues and limits must also be highlighted in order to, finally, facilitate the effective and widespread adoption and usage of the most innovative eHealth systems by patients, physicians and healthcare organisations.

This Special Issue presents innovative eHealth approaches and applications, which apply the most recent ICT technologies and techniques, such as IA, IoMT and others, to implement smart tools and methodologies to support the work of physicians and to promote the adoption of new eHealth tools in medicine and by healthcare organisations. At the same time, these contributions address the issues that usually affect this domain, like data privacy, the cyber security of the devices and healthcare infrastructures, the awareness and the involvement of medical personnel, etc. Therefore, the articles included in this Special Issue represent useful resources targeted to a multidisciplinary audience.

2. Published Articles

The main purpose of this Special Issue was to collect recent developments and research in the eHealth domain, presenting innovative approaches and applications while considering a multidisciplinary approach and multi-perspective views, including medicine, Information and Communication Technologies, Artificial Intelligence (AI), Internet of Things (IoT), Big Data Analytics, Cyber Security, and others. The focus of this Special Issue centres on the whole e-health domain.

In total, there were 13 contributions selected for this Special Issue (listed after Section 3), which propose innovative approaches and applications in the previously mentioned areas. These articles have been provided by researchers with broad expertise in different fields and backgrounds, such as medicine, informatics and engineering.

The published papers belong to the main specific areas of eHealth, while some papers present multidisciplinary approaches; therefore, they are included in more than one area: (i) COVID-19 classification; (ii) Artificial Intelligence; iii) Medical Imaging; (iv) Fractal Analysis; (v) Internet of Medical Things (IoMT); (vi) Machine Learning; (vii) Cyber Security; viii) Mobile Medical Apps; (ix) Scientific Literature Retrieval; and (x) Large Language Models. A summary of the papers published in this Special Issue is presented below.

Silvestri et al. (contribution 1) described a complex Deep Learning architecture, whose main aim is to improve the eXtreme Multilabel Text Classification problem [26] related to the classification and large-scale semantic indexing of scientific articles in PubMed [27]. In detail, the authors proposed an architecture called the Hierarchical Deep Neural Network (HDNN), which reproduces the same topology of the label set, in the case where this set is hierarchically organised (such as the MeSH adopted by PubMed). The experimental assessment performed by the authors compared the performances of the proposed HDNN with a classic flat CNN DL architecture for text classification when applied to task of semantically indexing PubMed articles. The results showed that the HDNN outperforms the CNN, in particular in the cases of hierarchical measures, demonstrating that, when a hierarchical label set is available, the reproduction of the label hierarchy directly into the DL architecture provides significant benefits. On the other hand, this complex and deep architecture has a high computational time, due to the need, during training, of propagating the weights calculated in a certain level to the next level before updating the weights of the next level of the HDNN architecture. Therefore, a more efficient parallel architecture is foreseen as an area of future work by the authors.

The contribution of Inigo Lopez-Gazpio (contribution 2) introduced an innovative Problem-Based Learning (PBL) methodology to enhance the teaching of Android programming education, specifically tailored for the development of nutritional applications.

The main novelty of the proposed approach is the integration of advanced programming concepts with practical application development, fostering deeper understanding and engagement among students. In detail, this application allows the programmers to access extensive and detailed nutritional information from different open-access food databases. The proposed approach was tested in a research project that involved third-year students of the Computer Science faculty at the University of Deusto in Spain. The students were engaged in the development of applications aimed at improving access to nutritional knowledge. The preliminary results of this research indicated a significant improvement in student engagement and learning outcomes compared to traditional teaching methods, underlining the possible use of this methodology in fostering research and advancing educational practices in computer science. The findings not only provided insights related to the unique challenges associated with Android programming, but also suggested possible customised educational strategies that can optimise the learning experience.

Alourani et al. (contribution 3) presented a framework for the efficient management of IoMT devices over an Information Centric Network (ICN). The current massive traffic growth generated by IoMT causes challenges related to the transmission of these data [12]. An approach to reduce IoMT traffic is the adoption of ICN [28], which leverages persistent naming multicast communication and thus reduces the response time. In this way, ICN used for IoMT can reduce the overhead due to the distribution of commonly accessed content. On the other hand, the excessive and unbalanced energy consumption of the IoMT devices that the ICN could cause can degrade the performance of the network. To address this issue, the authors presented a framework called the Dynamic Cache Scheme (DCS), which implements energy-efficient cache scheduling in IoMT over ICN with the aim of reducing network traffic and mitigating energy-related issues. This framework establishes a balance between multi-hop traffic and data item freshness by leveraging an effective use for caching in IoMT. The authors tested several parameters, such as the cache–hit ratio, stretch and content retrieval latency, comparing the obtained results with the current state of the art. The results demonstrated that the DCS approach outperforms the compared models in terms of the cache–hit ratio, stretch and content retrieval latency. The authors also assessed its possible adoption in other domains and scenarios.

Viana dos Santos Santana et al. (contribution 4) compared different ML models for the correct classification of COVID-19 and influenza (which present similar symptoms) during coexisting outbreaks in Brazil. In detail, they tested Decision Tree (DT), Multilayer Perceptron (MLP), Gradient Boosting Machine (GBM), Random Forest (RF), eXtreme Gradient Boosting (XGBoost), K-Nearest Neighbors, Support Vector Machine (SVM), and Logistic Regression algorithms on real COVID-19 and influenza datasets, which are openly available and were acquired by Brazilian healthcare. The obtained results were also assessed using a 10-fold cross-validation method, which increased their confidence. Finally, the authors analysed and commented on the obtained results, highlighting some specific features of each tested approach, and providing useful hints for the adoption of ML-based systems in the decision-making processes of physicians and policy makers.

The paper from Karagiannis et al. (contribution 5) discusses the cyber security issues related to the transmission of standard DICOM (Digital Imaging and Communications in Medicine) medical images. The universal adoption of DICOM images has revolutionised digital imaging in medicine, providing standard tools for the storage, sharing and transmission of both medical images and their related data (included, in a standard way, into the DICOM tags of the image). On the other hand, the implementation and deployment of the DICOM protocol often suffer from incomplete understanding, causing cyber security vulnerabilities within the healthcare ecosystem [29]. The authors of the paper proposed a specific implementation of DICOM for the communication of images and their related data to the PACS (Picture Archiving and Communication System) servers, whose main purpose is to address possible cyber threats. Moreover, they also implemented a simulation environment which is able to produce network traffic related to the use of the DICOM protocol. Overall, the resources provide the researchers with an advanced platform for the

implementation of security control tests for evaluating the robustness of security measures, identifying vulnerabilities, and testing security configurations. In this way, they gain a comprehensive understanding of DICOM communication and its practical implementation. Finally, the generated traffic allowed for the creation of realistic datasets, which are useful for the development of ML, and anomaly detection techniques.

Suvirtat et al. (contribution 6) investigated the use of Large Language Models (LLMs) for coding inpatient diagnoses. ICD coding is very useful for several tasks, ranging from statistical analysis to clinical research or medical billing, as well as for ensuring and improving the interoperability of medical documents. Moreover, the application of ICD coding is often mandatory for several official documents in many countries. The automatic application of ICD coding is not an easy task due to the very large number of codes; moreover, the complexity of clinical and medical language, which is used in many documents that must be tagged with the corresponding ICD codes, makes this task more difficult. The paper presented an analysis of the performance of three LLMs (mBERT [30], Multilingual E5 [31] and MEDPSU-RoBERTa [32]), examining their performances on a very large Thai language dataset formed from inpatient admissions. The results showed satisfactory results and confirmed that MEDPSU-RoBERTa, which is a domain-specific model, is able to achieve the best results. The results also highlighted that the performances are strictly dependent on the datasets, obtaining more accurate results in the cases of codes with larger number of samples, while the rarity of certain diseases (and corresponding documents in the datasets) posed challenges to accurate coding. Finally, the results underlined the difficulties when the models are faced with long clinical documents.

Czekster et al. (contribution 7) produced work focused on the security of IoMT devices, presenting a systematic literature review of Risk Assessment approaches specifically devoted to the IoMT. IoMT devices can be very effective instruments in supporting the remote management and care of patients; on the other hand, as they are able to collect and transmit sensitive data, they have critical and strict security requirements. While classic cyber security Risk Assessment approaches can be exploited to identify and assess potential risks, they are not able to manage sophisticated cyber-attacks in near real time. In these latter cases, Dynamic Risk Assessment (DRA) approaches [33] are more suitable for tackling the risks to patients when using IoMT devices. The authors produced a detailed literature review of RA related to the IoMT, highlighting the current trends and the more recent approaches in this field. In more detail, the review first focused on the significant ways of mitigating the impact of unauthorised intrusions, protecting end-users from personal data leakage and ensuring the device usage continuity. Furthermore, the paper identified the main research directions for DRA, addressing the challenges related to the dynamic infrastructures and the uncertain attack surfaces, with the aim of improving user protection and preventing cyber attacks.

The contribution from Pervan et al. (contribution 8) described a DICOM-based medical image communication system named Medical Imaging and Diagnostics on the Move (MIDOM). The proposed system includes some enhancements based on evolutions of the custom lossless Classification and Blending Predictor Coder (CBPC) [34] compression method previously developed by the same authors. Moreover, the MIDOM system was also integrated with Orthanc [35], a lightweight DICOM server, and a medical images-storing PACS server. The proposed system was tested on five real-world anonymised medical image sets, evaluating compression ratios and latency reduction, with the aim of simulating scenarios where medical service availability might be severely limited. The obtained results in all scenarios demonstrated that MIDOM, exploiting the included compression methods, was able to lower the network latency by at least 60% with respect to the transmission of raw and uncompressed image sets, allowing, at the same time, the perfect reconstruction of medical images.

Karagiannis et al. (contribution 9) described Chidroid, a mobile Android application whose purpose is retrieving, collecting and distributing logs from smart healthcare devices in the domain of the IoMT. The growing adoption of IoMT-connected devices in healthcare

has also caused an increase in cyber attacks [36], which could potentially provide attackers with access to patients' Personal Health Information (PHI) [37]. The approach described in this paper allows for the creation of datasets, semi-structured data or structured data from unstructured data. These datasets can be very useful for the development of AI methods for detecting cyber security threats and vulnerabilities and mitigating them. Moreover, Chidroid can be used as a policy-based tool to analyse the security issues in the most recent versions of Android. The tests performed demonstrated the effectiveness of the application, which retrieves logs and system metrics from several IoMT devices. Finally, the paper presented a method to perform a security analysis on Android devices that uses minimal system resources and reduces battery consumption.

The study from Fordellone et al. (contribution 10) focuses on an entropy-based fuzzy clustering technique for interval-valued data (EFC-ID) for cancer detection. The early detection of cancer can improve the chances of successful treatment, and screening techniques have the purpose of identifying possible signs of specific cancers or pre-cancers before symptoms have developed. On the other hand, precise detection mainly relies on human experience, and is thus affected by human and visual inspection errors. The authors tested the proposed clustering approach on the Breast dataset, demonstrating that EFC-ID can obtain better results compared to FKM in terms of several metrics (AUC, sensitivity and specificity). Moreover, further experiments on the Multiple Myeloma data demonstrated that EFC-ID outperforms the classic FKM in terms of Chi-squared, Accuracy rate and Adjusted Rand Indexes. The obtained results confirmed that the proposed EFC-ID is able to correctly identify the natural partition.

Contaldo et al. (contribution 11) presented a review paper that reports on the recent literature on the applications of fractal analysis devoted to the diagnosis of oral cancer and Oral Potentially Malignant Disorders. In the case of fractal analysis applied to diagnostics, the Fractal Dimension (FD) is usually calculated as a measure of the degree of regularity of a tissue or structure [38]. This feature can be applied to the analysis of lesions (such as oral lesions) to determine the degree of irregular tissue/vascularisation derailment; physicians correlate this with the nature of the lesion with the aim of identifying possible cancerous lesions. This paper evaluates the recent published literature on the fractal analysis of oral cancer and its precursors, namely Oral Potentially Malignant Disorders (OPMDs), investigating the specific FD that can be predictive of cancer and OPMDs. The authors only considered articles from three literature databases (Scopus, PubMed and Web of Science), and investigated according to the PRISMA checklist to analyse if fractal analysis can support the diagnosis of oral cancer and, moreover, if it can distinguish it from its precursors. The results of this review highlighted that fractal analysis, when applied to oral oncology, is promising, because it can be adopted as an effective and noninvasive diagnostic and prognostic tool for various premalignant lesions, especially for measuring the progression of premalignant lesions and OPMDs [39].

Kioskli et al. (contribution 12) framed the current state of cyber hygiene, explaining the related context and habits of end-users. They then proposed several best practices that should be adopted by healthcare organisations and professionals in order to achieve a high level of cyber hygiene, particularly regarding human-centric approach. Currently, critical healthcare infrastructures are very vulnerable to cyber attacks [40], as demonstrated by the several successful cyber attacks in recent years. Many of these are caused by a lack of awareness and incorrect behaviours on the part of end-users, who do not adopt the required level of cyber hygiene, i.e, regularly and promptly applying software updates, or adopting unique and strong passwords. Thus, the issues faced in this paper are of great importance and urgency, considering the large and increasing number of cyber attacks in the healthcare domain; these are very often caused by human errors. Therefore, cyber education can prevent many of the issues caused by poor cyber hygiene. On the other hand, cyber security and hygiene eduction for non-expert users (such as in the case of the healthcare domain) should adopt human-centric approaches to be more effective. Therefore, this paper firstly reports the best practices that should be adopted by healthcare organisations

and professionals to achieve a high level of cyber hygiene. Moreover, it explains how these best practises could be applied in a use-case scenario with the aim of improving awareness about privacy and cyber security. Finally, the authors presented their long-term vision based on human-centric approaches, which aims to facilitate the development of efficient practices and education associated with cyber hygiene, leveraging a flexible, adaptable and practical framework.

The article from Junaid et al. (contribution 13) is a review of the more recent advances in Artificial Intelligence and Wearable Sensors in Healthcare Delivery. The combined use of AI and IoT in healthcare allows for defining frameworks and solutions for the smart analysis of health and clinical data, improving the work of physicians and providing additional evidence for clinical decisions. Therefore, the authors highlighted how the application of AI and the IoT has changed healthcare service delivery from the traditional hospital-centred model to a personal portable device-centred model. In detail, this literature review highlights how recent research describes the advantages of embracing AI techniques and wearable sensors in tasks related to innovating and optimising the analysis of health and clinical data. Moreover, the review also discusses some challenges related to the issues of using AI and the IoT applied to healthcare data analysis. Finally, it identifies some issues and opportunities for future work.

3. Future of eHealth Applications and Approaches

This Special Issue gathered several studies in the field of eHealth, and the results of the published research describe interesting innovative approaches and applications from this domain. This Special Issue also underlines some of the issues that remain, as well as some risks and limits, proposing possible solutions.

In detail, some of the presented papers focused on Artificial Intelligence and Machine Learning applied to medicine and care applications, such as COVID-19 classification (contribution 4), biomedical scientific literature semantic indexing (contribution 1), the early detection of breast cancer (contribution 10) and reviewing the more recent combined use of Artificial Intelligence and IoMT wearable sensors in healthcare (contribution 13). Other papers considered eHealth cyber security, proposing a simulation environment to test DICOM communication and evaluate the related risks (contribution 5), producing a literature review of the cyber security issues of IoMT devices (contribution 7) and framing the current state of cyber hygiene in the eHealth domain, proposing a human-centric approach for the effective education of non-expert users on the best cyber security practises (contribution 12). One published paper reviewed the application of a Fractal Analysis methodology for oral cancer diagnosis (contribution 11). Another paper proposed a traffic and energy optimisation for IoMT devices (contribution 3). A study that describes the use of LLMs for automatic ICD-10 classification was presented in contribution 6, comparing them on a very large Thai language dataset formed from inpatient admissions. Two applications were, respectively, described in contribution 8 and contribution 9, presenting, in the first case, a DICOM-based medical image communication system enhanced with advanced compression methods, and, in the latter case, an Android application for the collection and distributions of logs from IoMT devices, tailored to analyse their cyber security issues. Finally, an approach to support the development of applications related to the nutritional domain has been presented in contribution 2.

The eHealth domain, thanks to evolutions in its technologies and the methods, is constantly evolving, and, therefore, new volumes of this Special Issue have been planned for the future.

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