


Nishu Gupta • Sumita Mishra  
Editors

# Internet of Everything for Smart City and Smart Healthcare Applications

 Springer

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ISSN 1860-4862                      ISSN 1860-4870 (electronic)  
Signals and Communication Technology  
ISBN 978-3-031-34600-2              ISBN 978-3-031-34601-9 (eBook)  
<https://doi.org/10.1007/978-3-031-34601-9>

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# Foreword

I am pleased to write this foreword as I find that the book deeply emphasizes the state-of-the-art technologies that comprise many research explorations in the field of Internet of Everything that widely includes ‘things’ as the major component and that it can offer in taking care of various applications through artificial intelligence, networking and automation.

I am confident that this book will provide an effective learning experience and a guided reference for researchers, professionals and students that are interested in the integration of artificial intelligence in IoT-based embedded technologies and its advances to the engineering field.

We encounter challenges in addressing technological problems. These challenges are both difficult and interesting. Researchers are working on them to develop new approaches and provide new solutions to keep up with the ever-changing potential threats. This book is a good initiative and a combined effort of a lot of authors across the globe. It provides a strong foundation to the existing and upcoming technologies, especially in the fields of smart cities and smart healthcare.

I highly recommend this book to a variety of audiences, including academicians, commercial engineers, researchers, students and scholars. It is my desire and expectation that this book will provide an effective learning experience, a contemporary update and a practical reference for all those who are interested in this versatile and trending field.

Wing Commander (Retd.), Deputy Pro Vice Chancellor,  
Amity University, Lucknow Campus,  
Lucknow, India

Anil Kumar

# Foreword

I am delighted to write the foreword for this edited book *Internet of Everything for Smart City and Smart Healthcare Applications*. This book highlights the importance of the Internet Technology, particularly the applications of the Internet of Things (IoT) towards smart cities and healthcare. The book intends to demonstrate to its readers useful applications and use-cases that cater to diversified technological requirements.

This book provides a window to the research and development in the field of “Internet for everyone” in a comprehensive way and enumerates the evolutions of contributing tools and techniques. The range of topics covered in this book is quite extensive and every topic is discussed by experts in their own field. The advances and challenges are discussed with a focus on successes, failures and lessons learned, open issues, unmet challenges and future directions.

Additionally, this book is a good initiative in a direction that addresses numerous issues related to IoT applications. I am convinced that this book will provide a solid platform to various realms of the existing and upcoming technologies, especially in the field of Smart Cities, Smart Healthcare, Artificial Intelligence, Human-Machine Interaction, Autonomous Vehicles and Intelligent Transportation. The authors can be confident that there will be many grateful readers who will have gained a broader perspective of the disciplines of machine interaction and its applications as a result of their efforts. I hope that this book will serve as a primer for industry and academia, professional developers, upcoming researchers across the globe to learn, innovate and realize the multi-fold capabilities of Artificial Intelligence and IoT applications.

I wish very good luck to the editors and contributors of this book.

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Manuel J. C. S. Reis

# Preface

The Internet of Everything (IoE) refers to devices or physical objects embedded with sensors and other technologies that connect and exchange data with other devices and systems over the Internet. Such devices are used for different applications including smart cities, smart healthcare, etc. to enhance the lifestyle of the people in terms of safer, sustainable and comfortable environment around us.

IoE is believed to integrate the novel futuristic trends at the cutting edge of study and research by featuring enormous applications in a proficient, adaptable and manageable way. It covers the primary mainstays of the Internet of Things (IoT) world giving a thorough description of the present advancements, systems and structures.

Written by international experts, this book intends to present to its readers about day-to-day and upcoming trends as an insight on the importance that IoT and Information and Communication Technology (ICT) solutions can offer towards smart city applications as well as in taking care of people's health proactively. Key features of this book include elaboration of recent and emerging developments in various specialization of curing health problems and their solutions; smart transportation systems, traffic management for smart cities, energy management, deep learning and machine learning techniques for smart health and smart cities, and concepts that incorporate Internet of Everything (IoTs and ICTs). The benefits of IoE solutions are enormous and the range of applicability is also significant. This book attempts to cover some useful IoE applications and architectures that caters to improved sustainability requirements.

The book is a perfect blend of a text as well as reference and suits to almost all levels of technical education and research as well as to novices interested in applications that Industrial IoT technologies can offer in the coming times thereby making almost everything smart, intelligent and self-adaptive. The book is divided into different parts having multiple chapters. The contents of the book have been organized in a reader-friendly manner. It is targeted at professionals, including university professors, graduate and Ph.D. scholars, industry practitioners and researchers, particularly in the field of computer communication, wireless communication, cyber-physical systems, machine learning and sensor networks.

The book attracted contributions from all over the world, and we would like to thank all the authors for submitting their works. We extend our appreciation to the reviewers for their timely and focused review comments. We gratefully acknowledge all the authors and publishers of the books quoted in the references.

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# Intangible Approaches to Improve Individual Health Indicators and Empower Caregivers



Carlos R. Cunha , André Moreira , Luís Pires ,  
and Paula Odete Fernandes 

## 1 Introduction

Populations worldwide are ageing at a faster pace than in the past, and this demographic transition will affect almost all aspects of society [1]. The number and proportion of people aged 60 years and more in the population are increasing; in 2019, the number of people aged 60 years and older was one billion; this number will increase to 1.4 billion by 2030 and 2.1 billion by 2050 [2]. Population ageing is an irreversible worldwide trend. This is the inevitable result of demographic transition, the trend towards longer lives and smaller families, which occurs even in countries with relatively young populations. In 2021, one in ten people worldwide was aged 65 and over; by 2050, this age group is forecasted to represent one in six people worldwide [3]. Globally, the number of people aged 80 years and over is increasing even faster than the number of people aged 65 years and over. By 2050, the world will have an estimated 459 million people aged 80 years and over, which is nearly triple the number in 2021, at approximately 155 million [3].

This finding was seen in all regions of the world where the number of older people increased rapidly between 1980 and 2021, a trend that is likely to continue for the next three decades [3]; even in Portugal, the proportion of older people as in other countries has been increasing steadily over the past decades. By 2050, Portugal expects an old-age dependency rate of 68.8%, which is one of the highest ratios in Europe [4]. The North interior of Portugal, namely, *Terras de Trás-os-Montes*, is following the same behaviour as what is being observed in the world and in Portugal. Since it is a region located in the northern interior of Portugal and is considered a

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region of low population density, it has been seeing an increase in the ageing index, and the ageing trends are evident. It is highlighted that in 2021, *Terras de Trás-os-Montes*' region presents an ageing index of 359.0 [5].

As fertility levels decrease, the percentage of younger people decreases, while the percentage of working-age adults and eventually older people increases. Population ageing is driven by more people living longer, healthier lives [3]. The increase in human life expectancy is a long-term trend, and survival at older ages has now become more widespread around the world. In general, an increase in the overall life expectancy reflects better health. The number of years lived in good health, or at least without severe disability, has increased in many parts of the world.

It is believed that every second person in the world holds anti-ageing attitudes, leading to poorer physical and mental health and reduced quality of life for older people, costing societies billions of dollars every year, according to the Global Report on Ageism, published by the World Health Organization (WHO) [1].

Given this concern with the significant increase in ageing, there is a need to promote and ensure people's well-being at all stages throughout the course of their lives. In this context, the role of technology has proven to be fundamental in the development of solutions for the promotion of medical health. Nevertheless, the role of technology in providing wellness care has emerged, as well as in helping caregivers, and different technologies have shown promise. The authors pointed out technologies such as the Internet of Things (IoT), extended reality (XR), virtual reality (VR), augmented reality (AR), mixed reality (MR) and machine learning (ML).

Following on from this, the purpose of this chapter is to present assignments aimed at the elderly population, prototyping technology-based solutions for creating mechanisms for measuring and promoting well-being. In addition, it presents support mechanisms for the activities of caregivers in nursing homes, as a way to empower caregivers and ensure better health and well-being.

This chapter is organized as follows: after this introductory section, a review of the relevant literature with regard to the use of emerging technologies to promote well-being and support the act of caring is presented in Sect. 2. Section 3 will present the conceptual foundations that will give rise to the prototyping approach. Next, in Sect. 4, the VR and MR prototypes, combined with ML, which were created to validate the conceptual model that was previously worked on, will be presented. Finally, some conclusions and final remarks that envision future work are presented.

## 2 Technology in the Context of Well-Being and Caregiving

The people's well-being plays a fundamental role in societies; however, few studies have been carried out on the relationship between well-being and technology [6].

In our opinion, we highlight the Internet of Things (IoT) which will support a whole re-engineering of how we can face well-being and the provision of healthcare and well-being. The use of XR has shown great potential for generating well-being –

VR has contributed to emotional and social well-being [7] and to stimulation, improvement and cognitive assessment [8], and according to [9], it can be a revolutionary tool for psychological interventions, having already been used in immersive therapies in mental disorders. MR, according to [10], is also identified as a contribution to support healthcare practices in nursing homes, where the use of MR glasses, combined with facial recognition, allows patient recognition and the automatic availability of relevant health data, to support caregivers' activities, thus ensuring caregivers' empowerment. Finally, the use of ML may allow, in a timelier manner, the detection of patterns of well-being or absence of well-being and, in this way, guarantee the increasing of proactivity in the detection of health and well-being problems, as well as providing medical or wellness care that maximizes physical and mental health.

The symbiosis between the use of technology and digital content has been transforming the health area, changing the ways of providing and obtaining healthcare, and, in this context, the use of XR, such as VR, can allow the assessment of behaviours, emotions and cognitions [7]. According to [8], using VR in experiences where comforting virtual environments are provided, which enhance calmness, seems to promote states of relaxation that, due to the little time people tend to have to relax, can be a very significant approach. In [9], a study is presented on the use of immersive and non-immersive strategies supported by VR in order to explore the emotional impacts when viewing 360° videos in age groups, highlighting the importance of positive emotions for better physical health and mental health of the elderly.

The importance of using technology is also highlighted in the caregivers' component, where several technologies have been introduced to improve the capacity to provide health and wellness services. This new reality leads to better and more personalized healthcare, but also to greater well-being for the elderly population who are often found in nursing homes. Training caregivers, formal or informal, with technology that allows them to act more proactively and efficiently should govern technology introduction strategies in the focused healthcare and well-being sector.

According to [10], MR also has great potential when we want to connect physically distributed caregivers who intend to achieve a shared goal. This is a typical scenario for situations where the caregiver needs to resort to other specialists to deal with situations that go beyond their competences – an example where MR can support collaborative work in a more immersive way.

As the area of health and well-being is information intensive, the use of artificial intelligence (AI), namely, techniques based on ML, is extremely promising due its ability to extract information and knowledge from raw data. This potential allows the detection of patterns of health and well-being translated by fluctuations and combinations of the most diverse biological and behavioural parameters. In this domain, the capacity for such detection is far superior to human capacity or to more conventional technologies based on pre-defined rules (i.e. by classical programming of computer applications).

The combination of technologies that allow creating immersive environments, rich in easily manipulated information and manipulated in a non-intrusive way to

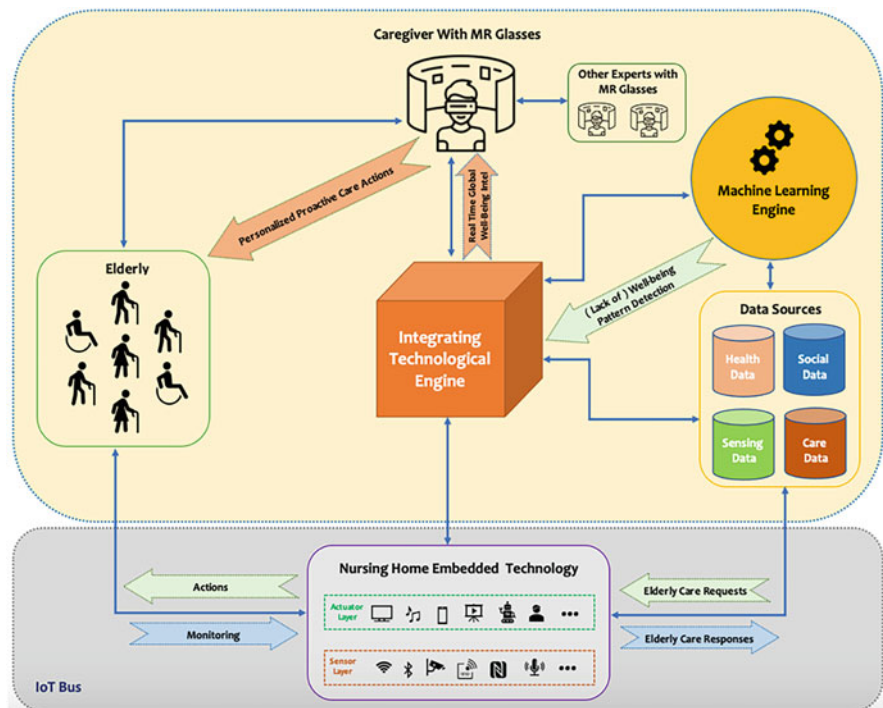


Fig. 1 Conceptual model. (Source: Authors’ own elaboration)

the normal performance of caregivers – VR, AR and MR – combined with the use of ML, will dictate, in our opinion, the way technology will be symbiotically allied with the health sector and the provision of healthcare and well-being. In this context, it is essential to think and design new information systems that take advantage of new technologies, creating innovative experiences that support new health and well-being practices that translate into increased well-being and empowerment of caregivers.

Next, the foundations that led to the development of a prototype are presented. These fundamentals present a conceptual model already presented in Fig. 1, which is summarized here in order to frame the developed prototype.

### 3 Conceptual Foundations

The conceptual foundations of this work – the conceptual model that have guided the development of a prototype – have already been published and are referred to as a way of better understanding the global vision that have supported the development of the prototype presented in the following chapter.

The conceptual model shown in Fig. 1 translates an integrated and cooperative vision of technology and support for cooperation between the different actors in the field of health and well-being. It is focused on the elderly and their caregivers, so it uses the concept of a nursing home as a test bed for its concepts.

The conceptual model starts from the credible principle that technology populates and will increasingly populate health and wellness spaces (e.g. nursing homes), making them increasingly smart spaces, where ubiquity and technological systems embedded in physical spaces will be a reality. In this context, it focuses its vision on the cooperative use of immersive technologies (e.g. MR glasses, such as the HoloLens<sup>®</sup> 2) capable of helping caregivers to access information and knowledge that allows them to act proactively. In addition, it proposes the use of immersive technologies (e.g. VR, AR) capable of creating immersive experiences of well-being in the elderly, contributing to the generation of emotional well-being.

This vision will tend to contribute to a better index of physical and emotional well-being that, along with all readings of biological parameters (medical acts), will feed full databases of information and knowledge about the elderly, as well as precious information for caregivers.

With the accumulation of data collected from the most varied sources, ideal scenarios will be created for the use of ML, which will enhance the detection of patterns of well-being or malaise. This detection will make it possible to personalize healthcare and anticipate scenarios of discomfort in a timely manner. In this way, we will be more efficient in providing healthcare and well-being.

## 4 Developed Prototype

This section presents the prototype that was developed to test the fundamentals of the conceptual model proposed in the previous chapter. Thus, Fig. 2 shows its general architecture. This prototype brings together a set of experiences using VR, AR and MR technologies combined with the use of ML. The architecture and implementation of various components of the prototype are explained in fine detail.

### 4.1 Database Layer

Although it is possible to have our own servers hosting the databases, thus giving total control over them, cloud services are used for this prototype. Among the databases used, the main one is a graph database system.

**Neo4j (Graph Database)** Is a NoSQL database with features common to this type of database such as flexibility, easily scalable and absence of pre-defined rigid structures as in relational databases, an aspect however that differentiates them from other NoSQL databases is the fact that graph databases are strongly relational, with

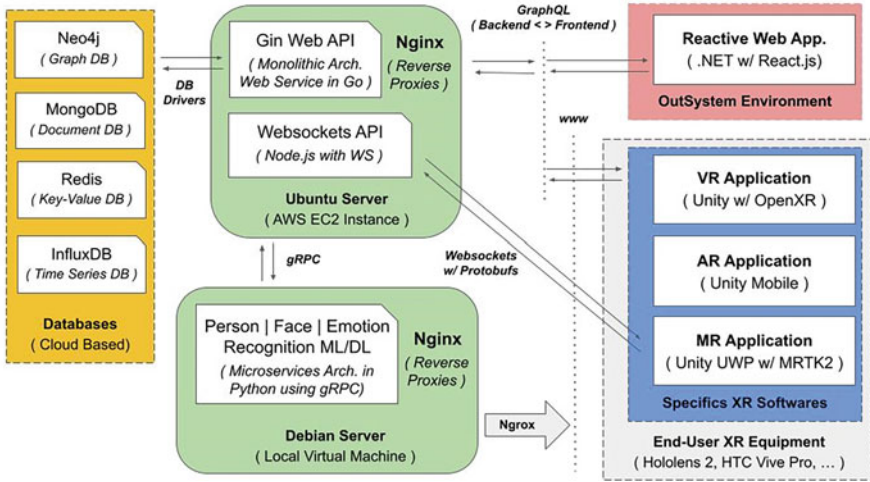


Fig. 2 Prototype overall architecture

an additional value being given to relations not seen in relational databases, that is, since they are based on the structure of graph data, they can also store “data”, which would be the equivalent of weight in graphs [11].

Among the providers of graph databases, the more popular and first on the market is Neo4j<sup>®</sup>, created in 2007, together with the concept of graph database, by Emil Eifrem, which, in addition to services such as a database, also aims to provide data science services, that is, taking advantage of the acquired data and its structuring to convert it into knowledge and predictions; some examples are from the use of spanning tree and the use of algorithms such as Leiden for communities’ detection.

One of the disadvantages of using graph databases in favour of relational databases is that they are limited to storing large volumes of text or numbers, as well as storing non-relational data.

**MongoDB (Document Database)** Is a NoSQL database, being one of the most known and adopted in its category, more specifically, MongoDB<sup>®</sup> is a document database, treating data as JSON documents and grouping them into collections, unlike of relational databases, this type of database does not have a direct way of implementing relationships between data, although it is possible with the cost of storage, but with a gain in the speed of reading data. This type of database, although often used as a direct substitute for relational databases, is however best used when storing non-relational data; in this prototype, MongoDB<sup>®</sup> is used to store data relating to 360° hotspots used in the application of VR, as well as large volumes of data that cannot be stored in the graph database.

**Redis (Key-Value Database)** Is a key-value database, also considered NoSQL, it is mainly used to store small volumes of data and assigned it to a key, its structure can be compared to the data structure known as a dictionary, with great speed to

access data and perform CRUD operations. Its use focuses on the implementation of VR session control through a Web application.

**InfluxDB (Time Series Database)** Is a time series database whose objective is to store temporal data for future analysis, being widely used for IoT environments, by storing data captured from various systems. The use of InfluxDB is foreseen to store data related to VR sessions whose objective is to capture temporal data, including sessions using eye tracking.

## 4.2 *Server Layer*

For the development of this prototype, two servers were prepared, the local one using Debian 11 operating system, recognized for its stability, while the one presented on the cloud, using the Amazon Web Services (AWS), runs the Ubuntu Server 22.04 LTS, while planned to use both servers with Debian 11 OS, there were problems to establish a remote development environment with AWS running an instance with the Debian 11 OS. The two servers have different focuses, and the main services configured on each of them are presented below.

**AWS EC2 Instance** Is an instance on Amazon Web Services, using Amazon's cloud services, it is running two Web APIs on different ports, both built on a monolithic architecture, with request control being carried using the reverse-proxy tool, Nginx®.

*Gin Web API* Is a Web API developed on top of Go/Golang using the HTTP Web framework Gin. This Web API is used by all applications developed for data transition between these and the databases, using a GraphQL architecture, which is considered a direct and simplified alternative to the REST architecture; among the differences between the two, some more highlighted reside on the fact that GraphQL only uses POST requests and only one route [12], it is known as a query language, and it is also based on graphs, thus creating a synergy with graph databases and solving some of the main problems attributed to GraphQL, in particular the N+1 Problem [13].

*WebSockets API* Is an API built on Node.JS® and using the WS library, although it is possible to use WebSockets in Go, at the time this component was developed, the library for using WebSockets was archived and without maintenance, thus choosing an option that had support as well as good performance [14]. Currently, WebSockets are used to communicate with the application in MR, so that it can send the captured frames to be analysed by ML and then the inference results are sent. This communication is done consistently through the use of Protocol Buffers, also known as Protobufs, which result in smaller data volumes and faster data transition compared to other commonly used serialization methods like JSON [15].

**Local Virtual Machine** Is a virtual machine running on a computer. This second server is needed due to the limitations of the free version of AWS as well as to create an environment closer to what real use will be. This virtual machine is exposed to the World Wide Web using Ngrok which exposes SSH access, for remote development, as well as a TCP port. In this server was used a microservice architecture, in contrast to the monolithic architecture present in the AWS EC2 instance, this approach was adopted since this server consists mainly in the use of ML models, each one with its focus and dependencies, requiring then scalability, easy maintenance and independence between them [16], being then developed a set of microservices in Python focused on the use of ML, as well as a “gateway”. These microservices communicate with each other using gRPC. This means of communication between services is also used for communication between the microservice described as “gateway” and the previously mentioned WebSockets API by using the exposed TCP port, which, after receiving the frame from the application in MR, will make a proto request to the “gateway”, to this will therefore be analysed by the ML models.

Although not used in this prototype, it is possible to use Nginx<sup>®</sup> for load balancing, in order to distribute requests across different gRPC servers, for example, when using clusters, in order to make better use of available resources. This server contains:

*“Gateway”/Image Inference* Is a Python microservice that receives the request from the WebSockets API and is responsible for the flow of the frame analysis, that is, this microservice will communicate with the others to make the inference on the frame and it will format the final response to be sent to the WebSockets API and therefore to the MR application. The defined flow is purposeful and planned in order to fulfil each ML requirement as well as to avoid unnecessary inferences.

*Person Detection* Microservice makes use of the YOLOv7 [17] model, from the YOLO family (You Only Live Once), state-of-art in real-time object detection and the most recent at the time of the development of the microservice; this will detect people, mobile phones and televisions, then filtering detections of people inside these electronic devices by comparing the bounding box, this filtering will avoid possible repeated detections of the same person as well as minimize people to be analysed by ML. Since during the development process of this prototype YOLOv8 was released (which demonstrates better results than its predecessor), an update is planned soon.

*Face Recognition* Is the second ML in the flow; this will receive the frame as well as the result of the inference made by the YOLOv7 model. For the development of this microservice, the DeepFace library was used, which provides various analysis methods around the Face, from identifying the person through comparison with a “database” of images [18] to predicting age or gender, using state-of-the-art models [19].

For this prototype, in order to receive only the necessary data, as well as optimize the code in terms of performance, and to take advantage of gRPC and asynchronous programming, parts of this library were reprogrammed, and, in the end, the ArcFace

[20] model was used to identify people in the frame within the bounding boxes defined by the person detection microservice. This detection will result in the acquisition of UUIDs corresponding to existing patients in the graph database. This same library is used for the detection of facial expressions, limited to anger, fear, neutral, sadness, disgust, happiness and surprise. After face detection and UUID acquisition, the person detection results, that is, the bounding boxes, are filtered so that only those that have people in the database continue to the next phase.

*Emotion Recognition* Is the last microservice in the flow using ML, this makes use of a PyTorch implementation of a CNN (convolutional neural network) by Abhishek Tandon based on the methodology proposed in the same article where the EMOTIC dataset is presented, this article proposes the recognition of emotions through the analysis of the person's body as well as the environment that surrounds him, giving importance to the context, thus resulting in two types of emotional detections, continuous and categorical, the latter making use of a list of 26 emotions while continuous refers to three emotional dimensions, valence, arousal and dominance, each evaluated from 0 to 10 [21]. This model makes use of the YOLOv3 model as well as CNN developed on the Places 365 dataset [22] with a focus on the analysis of the environment.

To make use of this model, it is necessary to have the person's bounding box pre-defined; thus, using the bounding boxes resulting from person detection and filtered by face recognition, after inferring the frame about these same bounding boxes, the emotions detected are then returned to the "gateway".

This model as well as the EMOTIC dataset cannot be used for commercial purposes; however, its use for non-commercial research is permitted.

In the final phase of the flow, the "gateway" will format the various data acquired so that they can be serialized to Protocol Buffers and sent to the WebSockets API; the returned data boils down to the UUID of the detected person; the list of emotions, continuous and categorical; and the bounding boxes for the person's face and body. Although the model used for the detection of emotions used is more specific, the diversity of possible emotions makes it more vulnerable to false detections, so it is planned to combine it with the result of emotional detection from face recognition in order to increase the possibility of accurate detections.

### 4.3 *End-User Applications*

At the end-user level, four applications are being developed, three of which fall under the category of XR applications with different users in focus, while the fourth is a Web application created for general use. The main equipment used to create immersive experiences are presented in Fig. 3.

**Web Application** Is being made using the low-code OutSystems platform; this allows the rapid development of the most common functionalities without losing the visual level; for this prototype, the most recent model is used, reactive Web



**Fig. 3** HTC® VIVE and HoloLens® 2 used equipment

application, which makes use of ReactJS with .Net, implementing functionalities that allow the execution of CRUD operations on the project's databases. Other more advanced features to be developed are:

- CRUD operations on the Faces database in the face recognition microservice
- Control over VR sessions through WebSockets
- Creation and manipulation of 360° hotspots as well as points of interest to be used in VR sessions using cloud storage and MongoDB®
- Visualization of data coming from data science results on Neo4j®

This application is focused on being used by different types of users, from caregivers in homes and doctors in hospitals to family members of patients.

**VR Application** Is a VR application being developed using OpenXR™ in Unity®, OpenXR™ being an API developed by Khronos® and supported by some of the main companies in the XR market, such as Meta®, HTC®, Valve™ and Microsoft®, with the objective simplify the development of cross-platform XR applications, that is, regardless of the type of headset used by the user. This application focuses on patients with the aim of conducting sessions to analyse their mental and health status.

Although in the current development phase the sessions are focused on the use of 360° hotspots with eye tracking, the objective is to implement the application in a way that can support other types of sessions such as using 3D scenarios; for this, a dynamic process is being planned to download all of the assets necessary for carrying out the session from a third server or cloud storage; these assets will vary from the 360° hotspots created in the Web application to 3D scenarios created in another context.

**AR Application** Refers to an application in AR; the purpose of this application is to be more accessible and for general use, since it can be used on most of the modern mobile phones.

Although the intention is to make use of AR, some of the foreseen functions are the use of Spectator View, that is, so that other people can see the same as caregivers without the need to use MR glasses as well as visualization of data from a closer to a mobile application.

**MR Application** Is a MR application developed in Unity® using MRTK2 (Mixed Reality Toolkit) developed by Microsoft®; although MRTK2 incorporates OpenXR™, the application is being developed with the HoloLens® 2 glasses as a target.

The application aims to assist medical caregivers, through the visualization of data corresponding to patients, among other functionalities that facilitate their work, as well as make use of the potential of technology. This application is structured in order to use mainly static classes and through the use of a managers/handlers architecture with a strong use of callbacks and actions.

As this is an application under active development and more advanced, some of the features, functional and non-functional, already implemented include:

*Embedded Database* refers to an object-oriented database called Realm developed by the MongoDB® team. The use of this database allows storing basic data in the application in order to be accessible even in situations where it is not possible to have an Internet connection; this type of concept is comparable to the use of SQLite in Android applications; however, SQLite is a relational database. Its use is being considered in the VR application, given the use of MongoDB® to store data related to VR sessions and the Realm SDK feature of synchronizing app data with MongoDB® Atlas.

*Pooling* is a term used in game development; it resumes with the reuse of GameObjects, such as 3D objects, that is, to minimize the use of the instantiate (GameObjects creation) and destroy (GameObjects destruction) methods that are found among the heaviest methods in terms of resource usage. Although it is an application and not a game, MR application makes use of this concept to reuse UI elements.

*UI Stackers* is the implementation of a logic equivalent to the operation of the UI in mobile applications, where the interfaces work as layers in stackers.

When developing games in Unity® and other game engines, UIs tend to be pre-defined and created from scratch with a static perspective, with only its content being changed, i.e. the flow of navigation UI works as if by a script, the same applies to mobile applications, however XR applications allow having N number of windows open, all of which can make use of the same interface, as well as with Web pages, in this way the existing interfaces in the MR application, as well as its components (buttons, input blocks, etc.) are pre-defined in a scriptable object that works as a dictionary of interfaces, from which the data referring to the interface needed to be instantiated are retrieved, among the stored data are references to the components, which are then updated the text and assigned Actions to the buttons, when this interface is no longer needed, more specifically the GameObject containing the interface. Will be put in “recycling” mode, that is, instead of being destroyed or given as non-existent, it will be placed in the Pool, and reused the next time that

interface is needed instead of creating a new one. This method allows to have a dynamic UI and minimize the consumption of resources, however this method alone does not create the mentioned logic by itself, to achieve this objective, whenever an instance is created this is also stored in a Stack data structure, when navigating via the interface, if a new window is opened, it will create a new Stack or replace the previous window, saving a reference to it in a variable in order to be able to create the interaction or navigation flow.

A more specific aspect at the level of development of interfaces for MR with MRTK2 that differs from other scenarios resides in the fact that the equipment used, in this case the HoloLens<sup>®</sup> 2 glasses, may be unable to provide a good user experience if sprites are used, a method common when assembling interfaces in Unity<sup>®</sup>, due to the difficulty of rendering them; in this way, the interface must be assembled using GameObjects with materials assigned, and these materials will then have the sprite as texture.

*QR Code Reading* allows the reading of QR codes through the use of the Microsoft.MixedReality.QR plugin present in the NuGet package manager; this functionality is currently used for user authentication; however, its potential is unlimited, and it can be used for situations from the simplest ones, such as viewing the list of patients present in a hospital room in a new window by reading the QR code placed at the door, to controlling IoT systems.

*Web API Client* is the implementation that allows the Unity<sup>®</sup> application to communicate with the databases, for this implementation was used the asset Best HTTP/2, developed by Tivadar György Nagy and present in the Unity Asset Store, the communication involves since POST requests in GraphQL till WebSocket connections.

*Notifications/Alert System* is a notification system that makes requests to the Web API, currently referring to medications to be given to patients under the caregiver's or institution's responsibility, the response to the request will be primarily stored in the embedded database and therefore created coroutines that run in the background as timers, once the time has elapsed, an interface will be instantiated as a pop-up alerting the timer, the possibility of implementing a geolocation system that allows the caregiver to find the patient referring to the notification is being analysed, although this moment system is used to alert about medication to be used, it is possible to integrate with IoT systems or create a means of communication between the patient and the caregiver, in scenarios, for example, where the patient needs help and alerts the caregivers through the use an application or an IoT system. When data is saved in the embedded database, the caregiver will not be limited to the Internet connection.

*Patients and Emotion Recognition* is the main and most advanced functionality implemented in the MR application, and consists of capturing frames in byte array format, that is, the scenario in front of the user using the MR headset, which is serialized to Protocol Buffers and sent to the WebSockets API where it will go through the analysis process in ML, a process exposed in previous sections, after the inference result is returned, also in Protocol Buffers, the message is deserialized, and through the data referring to the bounding box's an interface is instantiated at

the level of the patient's face demonstrating a material referring to the main emotion and a button through which a window referring to the patient's profile can be opened through the UUID.

Frame capture is performed through the `MediaFrameReader` class provided by the Windows Runtime API; this API is accessible given the fact that applications and games to be developed for HoloLens<sup>®</sup> 2 must be compiled with Universal Windows Platform (UWP) build settings; although there are other methods such as the use of the `PhotoCapture` class in Unity<sup>®</sup>, this method is the least expensive in resource consumption, with little effect on the application's performance; on the other hand, it delays development because it is necessary to compile the application in order to be tested, that is, it is not possible to test in Unity<sup>®</sup> itself.

After having the inference result, three methods are used to find the 3D location of the bounding box, the first method makes use of RayCast, however, although this method returns the correct direction, the distance is defined through the collision between the RayCast and the Spatial Mesh, called the Hit Point, however, while it identifies flat objects such as tables, chairs and computers, it does not recognize the shape of people, thus returning a false distance. The direction of the RayCast corresponds to the centre of the bounding box, which is converted to a 3D position; this method is based on the method used in the project made as proof of concept for the thesis "Mixed Reality Task Assistance for Pharmaceutical Laboratories using Markerless Object Tracking and Cloud Services" by Severin Pereto, named Lab Assist Vision, having been updated due to the use of deprecated methods and attributes.

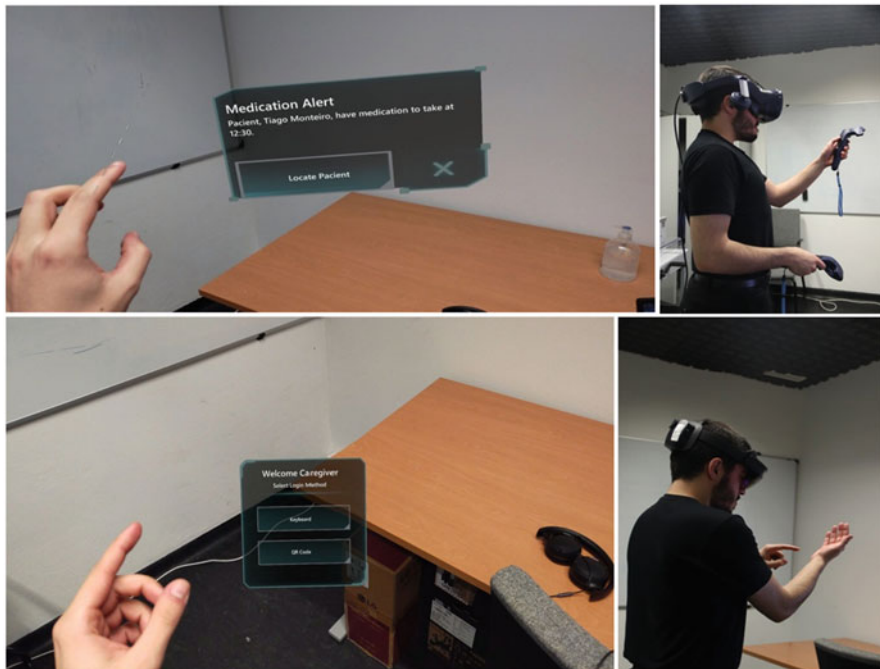
The second method is used to find the distance, this method is based on a sample project provided by Microsoft<sup>®</sup>, Holographic Face Tracking, however, this project makes use of FaceAnalysis API from Azure, as well as it is limited to one Face, this method complements the previous one given the fact that while the identified distance is close to the real one, the detected direction does not correspond to reality, this may, however, be due to the way the inference results are returned, not having been tested.

The third and final method boils down to merging the results of the two previous methods in order to receive a 3D position closer to reality; this method returns the position on the axis between the user and the hit point, with the same distance to the user as the distance between this and the position resulting from the second method; and this method can be compared with the method `Lerp` provided by Unity<sup>®</sup>.

Currently, this functionality is working; however, there are problems related to an offset on the axis Y depending on the distance between the user and the patient.

In the period of time between requests to the WebSockets API, computer vision is used to create a tracking system, currently using CSRT trackers provided by the OpenCV for Unity asset, developed by Enox Software, present in the Unity Asset Store, the tracking however is unstable in longer periods of time.

While in the first stages of the development, the WebSockets API was made in Python using the FastAPI framework and serializing the data in JSON, to improve the performance it was planned to make use of gRPC for direct communication between the MR application and the "gateway" microservice, and thus minimize the



**Fig. 4** Some pictures of the prototype used in a laboratory context

time between requests, however given deprecations and incompatibilities due to the .NET version used by Unity®, it was used Node.js® with Protobufs, at the moment its being solved problems related to the deserialization of the binary message in Unity®, when forwarded from the WebSockets API to the MR application.

In addition to the already developed and under development features mentioned, some plans include refactoring blocks of code for parallel computing using Unity’s job system package in order to take advantage of the HoloLens® 2 hardware, as well as the implementation of a method that allows the caregiver using the MR glasses to visualize the events in the patient’s VR session.

Some illustrative images of the prototype in operation, in a laboratory context, can be seen in Fig. 4.

## 5 Conclusion and Final Remarks

The rapidly growing number of people reaching older ages highlights the relevance of promoting health and disease prevention and the treatment of diseases over the life cycle, as conditions experienced earlier in life can have a substantial impact on a person’s life health and well-being in older ages. The concept of “healthy ageing”

outlines the importance of maintaining functional capacity as people age to enable their ongoing engagement in society.

The development of solutions capable of generating immersive environments has great potential to be used by the elderly to generate experiences that enhance emotional well-being. In addition, they allow the assessment of emotional and mental states. In a complementary perspective, the creation of applications based on XR to help caregivers is an approach to empowering these same caregivers.

In a world where the use of embedded technology in physical spaces grows and where technology begins to be an extension of our body, it is important to re-engineer thinking in the creation of new and innovative solutions that help the management and self-management of emotional states and mental and physical health, as well as help caregivers.

This work presents a prototype that has its conceptual foundations in a previously designed model, which takes advantage of alternative realities combined with ML, to demonstrate what can be done for an innovative vision in actors linked to health and well-being.

The next step will be testing in a real environment (i.e. in a nursing home), in order to adjust and validate the developed prototype, to measure its impact on improving the physical and emotional well-being of the elderly as well as to understand the level of help it represents for caregivers.

**Acknowledgement** This work is funded by the European Regional Development Fund through the Regional Operational Program North 2020, within the scope of Project GreenHealth-Digital strategies in biological assets to improve well-being and promote green health, Norte-01-0145-FEDER-000042. The authors are grateful to the FCT Portugal for financial support by national funds FCT/MCTES to UNIAG, under project no. UIDB/04752/2020.

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